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US Army Corps of Engineers
Waterways Experiment Station

Stochastic Vehicle Mobility Forecasts Using the NATO Reference Mobility Model

Report 3
Database Development for Statistical Analysis of the NRMM II Cross-Country Traction Empirical Relationships

by Jody D. Priddy

Prepared for Headquarters, U.S. Army Corps of Engineers

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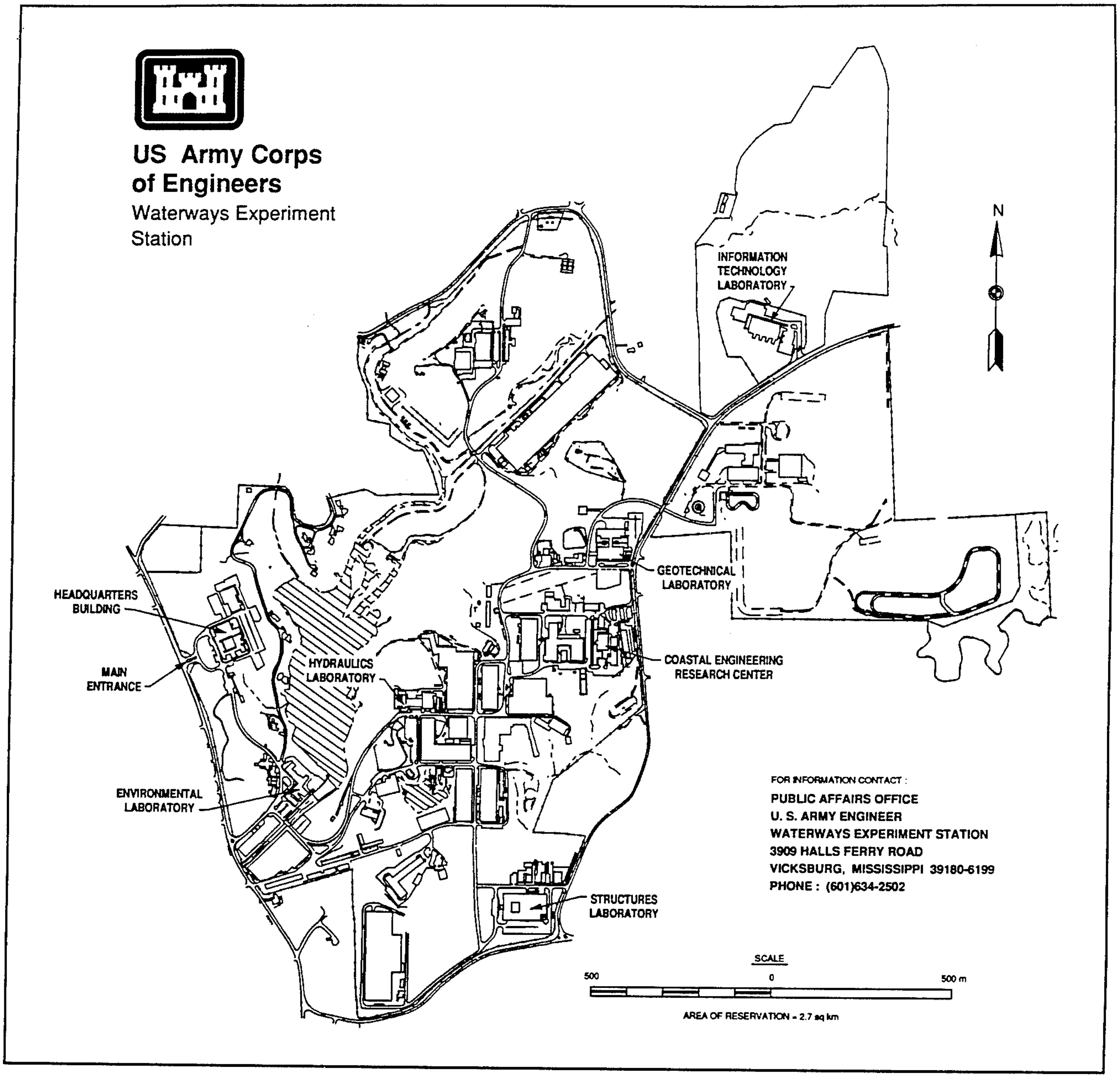

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Preface

Personnel of the U.S. Army Engineer Waterways Experiment Station (WES) conducted this research during the period October 1993 through September 1994 under RDTE Work Unit Number AT40-AM-010, entitled "Analysis and Verification of Pre-Release Stochastic Mobility Model." This work unit was a part of the larger Vehicle Terrain Interaction - AT40 (146) Work Package.

The study was conducted under the general supervision of Dr. William F. Marcuson III, Director, Geotechnical Laboratory (GL). The study was conducted under the direct supervision of Mr. Newell R. Murphy, Jr., Chief, Mobility Systems Division (MSD),GL; and Mr. Donald D. Randolph, Chief, Modeling & Methodology Branch (MMB), MSD. The principal investigator over the AT40-AM-010 Work Unit was Dr. Niki C. Deliman of MMB, and associate investigators were Mr. George L. Mason, Jr., and Mr. Richard B. Ahlvin, both of MMB.

The examination of the NATO Reference Mobility Model, edition II (NRMM II) empirical relationships and the development of the supporting databases were conducted by Mr. Jody D. Priddy of MMB. Support in the preparation of the databases was provided by Mr. Tommy Hutto, Mrs. Nora Ponder, Mrs. Pamela May, and Mr. Cedric Walls, MSD; and Mrs. Delina Harris, ARC. Numerous consulted experts mentioned in the introduction of this report provided invaluable historical guidance that immeasurably aided in the successful completion of this work.

This report was written and prepared by Mr. Priddy with the exception of the many bibliographical entries. These were prepared by Mrs. May.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
miles per hour	1.609344	kilometers per hour

1 Introduction

Background

Previous Work

This report documents the continued progression of a research effort aimed at developing stochastic vehicle mobility forecasting capabilities using the NATO Reference Mobility Model (NRMM). More specifically, this report documents: (1) the examination of the NRMM, edition II (NRMM II) empirical relationships for predicting vehicle traction on cross-country terrain and (2) the development of databases for use in characterizing the variability associated with these empirical relationships.

The driving motivation behind developing stochastic forecasting capabilities is the potential for viable use of NRMM as a tactical decision aid in a battlefield environment. In order for this to be viable, battlefield commanders and decision makers need not only rapid model predictions, but also some indication of the risk involved due to inherent variability in model inputs and in empirical relation curve-fits. Lessem et al. (1992) conveyed methods by which NRMM can be used to make stochastic vehicle mobility forecasts. A follow-up (Lessem et al. 1993) to that report presented refinements to the stochastic forecasting procedures, and it also presented the application of the newly refined procedures to two historical mobility assessments that were used in the procurement of some U.S. Army vehicles in use today. The follow-up report showed that the results of the two mobility assessments were unchanged by using the stochastic forecasting procedures, but it also showed that the stochastic output provided even more useful information that could have been used to assess (rank) the candidate vehicles.

The stochastic procedures presented in the two studies just mentioned characterized the variability of the empirical relationships using initial small-scale databases and/or judgement. The intent was to demonstrate the stochastic forecasting concepts rather than to reflect accurate output variability. The effort reported herein was conducted to facilitate a more accurate characterization of the variability in the cross-country traction empirical relationships with applicable, full-scale data sets, most of which were used in the original development of the relationships. When implemented into the stochastic forecasting procedures, variability characterizations based on these new data sets will more accurately convey the variability in model outputs.

Consulted Experts

To develop databases for characterizing the variability of empirical relationships, it is necessary to be familiar with (1) the test data used to develop the empirical relationships, and (2) the implemented use of the empirical relationships. Much of the information needed to get adequately familiar with many of the NRMM II empirical relationships has never been published. This is because the relationships were developed and improved over time from relatively small amounts of information as it became available without the luxury of structured parametric studies aimed specifically at their development. Another limitation is the fact that NRMM was molded into its current form over a span of more than 30 years from the ideas and efforts of many researchers, most of whom are retired, deceased, or no longer involved with NRMM. To overcome these limitations, some NRMM experts were consulted for information about the original data used to develop the empirical relationships and about the implemented use of the empirical relationships. It was also necessary to consult with current mobility testing experts in order to gather necessary information about the test data generated over the past 20 years. The following provides background into the efforts taken to gain adequate familiarity with the NRMM II empirical relationships and the available data, and it also provides acknowledgement to those who made contributions.

Mr. Barton G. Schreiner was contracted by MSD as an expert consultant in soils trafficability and vehicle mobility. His task was to provide historical guidance for the development of databases to be used in characterizing the variability associated with many of the NRMM II empirical relationships. Mr. Schreiner is a civil engineer who spent more than 30 years working in the area of soils trafficability and vehicle mobility at WES, and he retired as Chief of the Mobility Investigations Branch of MSD. He was one of the primary developers of the Fine-Grained Traction and Muskeg Traction relationships in NRMM II. During his experience with WES, he compiled and maintained historical files containing information used in the development of the original Vehicle Cone Index (VCI) relationships, AMC-71 (the first speed-predicting model), NRMM I, and NRMM II. Due to their significance, these historical files were maintained at MSD after his retirement. Mr. Schreiner's experience and his knowledge of the applicability of the historical files made his guidance in the information gathering vital to the development of the databases.

Mr. Schreiner's primary expertise is in fine-grained traction and muskeg traction. He provided firm guidance identifying the historical sources used in developing the Fine-Grained One-Pass VCI, Fine-Grained Drawbar at Nominal Slip, and Muskeg Traction empirical relationships. He also provided direction into what sources were used in developing the Fine-Grained Slip at "Maximum" Soil Strength and Tracked Vehicle Traction on Coarse-Grained Soils empirical relationships. The guidance Mr.

Schreiner provided was followed almost without exception during the data gathering, and once the databases for which he provided guidance were complete, he closely inspected the sources and the data and then approved the databases.

Dr. William E. Willoughby was also consulted as an expert in the area of soils trafficability and vehicle mobility. Dr. Willoughby is a senior Research Civil Engineer at MSD with over 25 years in vehicle mobility testing. His primary expertise is in the area of fine-grained traction, and he is one of the most experienced researchers for drawbar pull - slip testing on firm soils with slippery and non-slippery surface conditions. Dr. Willoughby was one of the two program managers over the Wheeled versus Tracked Test Program (Willoughby et al. 1991) which was the largest field-conducted mobility research program ever conducted by WES and which generated 40% or more of all the available fine-grained traction data. The Wheeled vs. Tracked Program was also the key event that led to the significant upgrade of NRMM from edition I to edition II. This experience and knowledge made Dr. Willoughby another crucial advisor in the information gathering for the databases.

A third major advisor was Mr. Richard B. Ahlvin of MMB. Mr. Ahlvin has been involved with the implementation of mobility modeling algorithms for over 20 years, and he implemented the new algorithms for the significant upgrade of NRMM from edition I to edition II. This high level of intimacy with the NRMM algorithms has resulted in Mr. Ahlvin becoming the custodian of the NRMM program code. This experience and knowledge made Mr. Ahlvin a crucial advisor in the examination of the NRMM II empirical relationships in terms of implementation.

Many sources of information were researched for the development of the databases such as WES technical reports, WES miscellaneous papers, and files retained at MSD on published and non-published studies. Several of the personnel involved with these researched studies are still members of MSD, as is the case with Dr. Willoughby, and when possible, these personnel were also consulted for guidance in the information gathering for the databases. The following personnel were consulted on the basis of their involvement in specific studies: Mr. Richard H. Gillespie, Chief of Mobility Investigations Branch (MIB) of MSD, and Messrs. Charles E. Green, Randolph A. Jones, Dennis W. Moore, George L. Mason, Jr., M. Wendell Gray, David M. Rogillio, Carl R. May, Robert H. Johnson, and David E. Strong.

Purpose

The purpose of this report is: (1) to provide a clear background into the fundamental origin, the implemented use, and the identity of the NRMM II empirical relationships for predicting vehicle traction on cross-country terrain and (2) to provide a permanent record of the developmental steps as well as the general contents and applicability of databases developed for use in characterizing the variability associated with these empirical relationships.

Scope

Almost all of the NRMM II empirical relationships for predicting vehicle traction on cross-country terrains are addressed in this report. The examined relationships comprise the bulk of the empirical relationships within NRMM II (70 of approximately 114). Four of the five cross-country vehicle/terrain interaction (VTI) categories are addressed:

(1) Vehicles on Fine-Grained Soils (includes Moist Sands with Fines),
(2) Tracked Vehicles on Coarse-Grained Soils (Arid Sands),
(3) Wheeled Vehicles on Coarse-Grained Soils (Arid Sands), and
(4) Vehicles on Muskeg.

The fifth cross-country VTI category is Vehicles on Snow. Snow VTI modeling has recently undergone significant changes by the Cold Regions Research and Engineering Laboratory (CRREL). These changes have been implemented into NRMM, and they are expected to be officially adopted by the NRMM Technical Management Committee in the near future. The test data necessary for analysis of CRREL's new relationships is currently not available at WES, and therefore, Vehicles on Snow was not included in the scope of this report.

Definitions

The following are definitions of specialized terms used in this report:

a. *All-drive [vehicle].* All assemblies (wheeled or tracked) are powered. For example, 4x4, 6x6, 8x8, etc.

b. *Assembly.* The combined elements for one single traction mechanism on a vehicle. It represents all of the wheels on a single axle typical of a wheeled assembly or the pair of tracks typical of a tracked assembly.

c. *Chameleon Parameter.* A parameter that has no single defined specific composition. Its general composition is fixed, but its specific composition changes as necessary to fulfill the needs of the current application. The following is an example:

chameleon parameter = λ

general composition = *soil strength and vehicle assembly characteristics*

specific composition = RCI_X *or* Π_P *or* Π_U, *etc. (See Notation at the end of this chapter)*

d. *Coarse-grained soil.* A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (larger than 0.074-mm in diameter).

e. *Cone index, (CI).* An index of the in situ shear strength of a soil.

f. *Contact Pressure Factor, (CPF).* A factor representative of the nominal contact pressure between a traction element and a rigid surface. For information on how this factor is computed refer to page 32 of Ahlvin and Haley (1992).

g. *Critical layer.* The layer of soil that contributes most significantly to vehicle performance. The depth of the critical layer is dependent upon vehicle and soil strength characteristics.

h. *Cross-Country Terrain.* Terrain not specifically improved for vehicular traffic (Meyer et al. 1977).

i. *Deflection correction factor.* A parameter that is related to a vehicle's VCI_1 performance on fine-grained soils. It corrects the predicted VCI_1 for tire deflections other than 15%, and it is computed as:

$$\textit{Deflection correction factor} = \left[\frac{0.15}{\delta/h}\right]^{0.25}$$

j. *Drawbar.* Used synonymously for drawbar pull coefficient.

k. *Drawbar pull, (D).* The amount of sustained towing force a self-propelled vehicle (or assembly or element) can produce on a given surface. It is a function of the surface and speed, and it is the net force derived from tractive force reduced by motion resistance.

l. *Drawbar pull coefficient, (D/W).* Drawbar pull divided by vehicle (or assembly or element) weight.

m. *Element.* A single traction component on an assembly. It represents a single wheel on a wheeled assembly or a single track on a tracked assembly.

n. *Excess cone index, (CI_X).* A parameter that is related to a vehicle's traction performance on muskeg soils and is computed as:

$$CI_X = CI - VCI_{1(MK)}$$

o. *Excess rating cone index, (RCI_X).* A parameter that is related to a vehicle's traction performance on fine-grained soils and is computed as:

$$RCI_X = RCI - VCI_{1(FG)}$$

p. *Fine-grained soil.* A soil of which more than 50 percent of the grains, by weight, will pass through a No. 200 US Standard sieve (smaller than 0.074-mm in diameter).

q. GO. The situation when a vehicle is able to make a desired number of passes (such as one pass for VCI_1) on a particular soil strength during a multi-pass test.

r. Gross vehicle weight, (GVW). Weight of a vehicle fully equipped, loaded, and serviced for operation including operating personnel.

s. Immobilization. The inability of a vehicle to independently move in any direction.

t. Maximum-Pull Slip. The value of slip used in NRMM II for computing the maximum tractive force that a vehicle can develop at zero velocity. It is usually implemented as a slip value that falls in the regions of slip where maximum drawbar pull coefficient occurs. It is not always 100% slip.

u. "Maximum" Soil Strength. The average soil strength characteristic of a data set used to develop an NRMM II Slip at "Maximum" Soil Strength empirical relationship. It is not necessarily a true maximum soil strength magnitude, and the range of soil strengths characteristic of the data set may be large, such as 300 to 750 RCI.

v. Mobility. The overall capability of a vehicle to move from place to place while retaining its ability to perform its primary mission (Meyer et al. 1977).

w. Mobility Index, (MI). A parameter that is related to the VCI performance of vehicles on fine-grained soils. It is composed of many traction influencing vehicle characteristics. For specific information on how MI is computed, refer to Ahlvin and Haley (1992).

x. Motion resistance, (R). Any force imposing resistance to the motion of a vehicle (or assembly or element). At the element level, it is composed of rolling resistance forces only.

y. Motion resistance coefficient, (R/W). Motion resistance divided by vehicle (or assembly or element) weight.

z. Muskeg (peatland). An organic soil consisting of a surface layer of living vegetation and a sublayer of peat of any depth and existing in association with various hydrological conditions (Meyer et al. 1977).

aa. Natural Soil Deposits. Soils that have been deposited and that have gained their current consistency by natural environmental means.

bb. NOGO. The situation in which a vehicle is unable to make a desired number of passes (such as one pass for VCI_1) on a particular soil strength during a multi-pass test.

cc. Nominal Slip. The slip at which the NRMM II Drawbar at Nominal Slip relationships are empirically based. It may or may not represent a desirable operating condition.

dd. Optimum drawbar pull coefficient, ($D/W_{Opt.}$). Drawbar pull coefficient at optimum slip.

ee. Optimum slip. Slip at which maximum work index occurs.

ff. Pass. A single, one-way trip of a vehicle over a test lane.

gg. Power-train. The mechanical components of a vehicle used for developing tractive force. It includes all components from the engine to, but not including, the traction elements.

hh. Powered-wheel/sand numeric, (Π_P). A dimensionless parameter that is related to the traction performance of wheeled vehicles on coarse-grained soils and is computed as:

$$\Pi_P = CI\left[\frac{(bd)^{3/2}n}{(1 - \delta/h)^3\,W}\right]SS_{CF}$$

ii. Prepared Soil Deposits. Soils that have been mechanically processed and/or placed so that they demonstrate a specific, desired consistency.

jj. Rating cone index, (RCI). The measured cone index multiplied by the remolding index; it expresses the soil strength rating of soil subjected to sustained traffic (Meyer et al. 1977).

kk. Rolling resistance. Motion resistance that is due to deformations in the terrain (external) and in the traction elements (internal).

ll. Slip. An indication of how the speed of the traction elements differs from the forward speed of the vehicle. It is defined by the equation (Meyer et al. 1977):

$$Slip = \left(\frac{r_R\omega - v}{r_R\omega}\right)$$

where: r_R = *rolling radius*

ω = *angular velocity of the wheel or number of revolutions per unit time divided by* 2π *for a track*

v = *forward velocity of vehicle or wheel axle*

mm. Soil gradient, (G). The average slope of the cone index versus depth profile.

nn. Soil strength correction factor, (SS_{CF}). A correction factor used to modify soil strength based on the effects of multiple assembly passes. For specific information on how SS_{CF} is computed, refer to Ahlvin and Haley (1992).

oo. Tire stiffness factor, (X_{TS}). A dimensionless factor that is related to the additional stiffness of a tire due to the tread and is expressed as a motion resistance coefficient. It is computed as:

"flexible" tires (typical radials)	$X_{TS} = 0.05\left(\frac{\delta}{h}\right)$
"medium" tires (typical bias ply)	$X_{TS} = 0.2\left(\frac{\delta}{h}\right)^{1.4}$
"stiff" tires (solid rubber)	$X_{TS} = 0.4\left(\frac{\delta}{h}\right)^{1.6}$

pp. Track/sand numeric, (Π_T). A dimensionless parameter that is related to the traction performance of tracked vehicles on coarse-grained soils and is computed as:

$$\Pi_T = 0.6\left(\frac{0.8645}{3.0}\,CI\right)\frac{(bl)^{3/2}}{\frac{1}{2}W}$$

qq. Traction. The vehicle/terrain interaction process used to produce vehicle motion relative to the terrain.

rr. Tractive force, (T). The force developed at the element/terrain interface of a vehicle for producing motion of the vehicle parallel to the terrain.

ss. Trafficability. The ability of terrain to support the passage of vehicles (Meyer et al. 1977).

tt. Unified Soil Classification System, (USCS). A system which identifies (classifies) soils according to their textural and plasticity qualities and to their grouping with respect to their performances as engineering construction materials (Meyer et al. 1977).

uu. Unpowered-wheel/sand numeric, (Π_U). A dimensionless parameter that is related to the traction performance of wheeled vehicles on coarse-grained soils and is computed as:

$$\Pi_U = \frac{\Pi_P}{1 - \frac{b}{d}}$$

vv. Vehicle cone index, (VCI). Minimum soil strength in the critical layer, in terms of rating cone index for fine-grained soils or in cone index for coarse-grained soils and muskeg, required for a specific number of passes of a vehicle, such as one pass (VCI_1).

ww. Vehicle-file. Input data file for NRMM that contains all of the vehicle characteristics necessary for model predictions.

xx. *Weight over perimeter factor, (W/P).* A factor that is related to the VCI performance of vehicles on muskeg soils, and is primarily based on the punching resistance of the upper vegetation layer. It is computed as:

wheeled vehicle assemblies: $$\frac{W}{P} = \left[\frac{W}{(b + d)n}\right]$$

tracked vehicle assemblies: $$\frac{W}{P} = \left[\frac{W}{b + l}\right]$$

yy. *Wheel/clay numeric, (β).* A dimensionless parameter that is related to the traction performance of wheeled vehicles on fine-grained soils and is computed as:

$$\beta = \frac{RCI\, b\, d}{\frac{W}{n}\left(1 + \frac{b}{2d}\right)}\sqrt{\frac{\delta}{h}}$$

zz. *Work index.* A dimensionless number that indicates how efficiently a vehicle produces drawbar pull and which is computed as:

$$Work\ Index = \frac{D}{W}\left(1 - \frac{Slip(\%)}{100}\right)$$

Acronyms

The following are acronyms used in this report:

a. *AMC-71.* The AMC '71 Mobility Model.

b. *NRMM II.* NATO Reference Mobility Model, edition II.

c. *TMR.* Towed Motion Resistance (as in the test).

d. *USCS.* Unified Soil Classification System.

e. *VTI.* Vehicle/terrain interaction.

f. *WES.* Waterways Experiment Station.

Notation

The following are notation used throughout the text, figures, tables, and plates of this report:

A_P total number of powered assemblies on a vehicle

A_U	total number of unpowered assemblies on a vehicle
A_{XZ}	projected stress area in the XZ plane
A_{YZ}	projected stress area in the YZ plane
b	nominal tire section width for wheeled assemblies or track width for tracked assemblies
CF	correction factor used to convert tractive force coefficients to drawbar pull coefficients
CI	cone index
CI_X	excess cone index above VCI_1
CPF	contact pressure factor
d	nominal outside tire diameter
D	drawbar pull force
D_{Soil}	"soil limited" drawbar pull force for a vehicle
D/W	drawbar pull coefficient
$\frac{D}{W}$	drawbar pull coefficient
$\frac{D}{W}{}^{CI}_{Nom.}$	drawbar pull coefficient at Nominal slip and a specific cone index (computed using the Drawbar at Nominal Slip empirical relationships)
$\frac{D}{W}{}^{RCI}_{Nom.}$	drawbar pull coefficient at Nominal slip and a specific rating cone index (computed using the Drawbar at Nominal Slip empirical relationships)
$\frac{D}{W}{}^{SS}_{Nom.}$	drawbar pull coefficient at Nominal slip and a specific soil strength (computed using the Drawbar at Nominal Slip empirical relationships)
$\frac{D_P}{W_P}{}^{SS}_{Nom.}$	summed drawbar pull coefficient at Nominal slip and a specific soil strength for all of a vehicle's powered assemblies
$\frac{D}{W}{}^{"Max"}_{Nom.}$	drawbar pull coefficient at Nominal slip and "Maximum" soil strength for a vehicle (computed using the Slip at "Maximum" Soil Strength relationships)
$\frac{D}{W}{}^{"Max"}_{MP}$	drawbar pull coefficient at Maximum-Pull slip and "Maximum" soil strength for a vehicle (computed using the Slip at "Maximum" Soil Strength relationships)
$\frac{D}{W}{}^{SS}_{???}$	vehicle drawbar pull coefficient at unknown (???) slip and a specific soil strength

GVW_P	gross vehicle weight on powered assemblies
h	nominal tire section height
i	subscript indicating the i-th assembly
j	subscript indicating the j-th stress component
k	subscript indicating the k-th tractive force speed point
l	track length in contact with the ground
MI	mobility index
n	total number of tires on a wheeled assembly
N	normal force
NC	total number of stress components
P_i	subscript indicating the i-th powered assembly
Q	torque
R	motion resistance force
RCI	rating cone index
RCI_X	excess rating cone index above VCI_1
R/W	motion resistance coefficient
$\frac{R}{W}^{CI}$	motion resistance coefficient at a specific cone index
$\frac{R}{W}^{RCI}$	motion resistance coefficient at a specific rating cone index
$\frac{R}{W}^{SS}$	motion resistance coefficient at a specific soil strength
$\frac{R_P}{W_P}^{SS}$	summed motion resistance coefficient at a specific soil strength for all of a vehicle's powered assemblies
$S^{App.}$	apparent ("theoretical") speed of a vehicle
S^{True}	true ("slip corrected") speed of a vehicle
$Slip^{"Max"}$	vehicle slip at "Maximum" soil strength
$Slip^{SS}$	vehicle slip at a specific soil strength
SS	soil strength
SS_X	excess soil strength above VCI_1

SS_{CF}	soil strength correction factor for multiple assembly passes
T	tractive force
T_{MAX}	"soil limited" tractive force for a traction element
T_{Soil}	"soil limited" tractive force for a vehicle
$T_{Vehicle}$	maximum tractive force that can be generated by a vehicle's power train
U_i	subscript indicating the i-th unpowered assembly
VCI_1	one-pass vehicle cone index
$VCI_{1(FG)}$	one-pass vehicle cone index for fine-grained soils
$VCI_{1(MK)}$	one-pass vehicle cone index for muskeg soils
$\frac{W}{P}$	weight over contact perimeter
W	assembly weight
W_W	wheel load
X_{TS}	tire stiffness factor
β	wheel/clay numeric
δ	hard-surface tire deflection in inches
Δ	shift constant for the Slip at "Maximum" Soil Strength relationships
θ	slope angle of inclination
μ	coefficient of friction, or maximum tractive coefficient
Π_P	powered-wheel/sand numeric
Π_T	track/sand numeric
Π_U	unpowered-wheel/sand numeric
σ	normal stress
σ_X	normal stress component in the X direction
σ_Y	normal stress component in the Y direction
τ	shear stress
τ_X	shearing stress component in the X direction
τ_Y	shearing stress component in the Y direction

2 The Empirical Relations

With the key purpose of this study being to develop databases for characterizing the variability of the NRMM II empirical relationships for cross-country traction, the first logical step was to determine what the relationships are. For a full understanding of the empirical relationships, one should not only understand what the relationships are, but also what the fundamental origins of the relationships were. Furthermore, in order to facilitate an appropriate analysis of the variability of the empirical relationships and to determine the propagation effects of this variability throughout NRMM II predictions, it was necessary to determine the implemented use of the relationships.

NRMM Cross-Country Traction Basics

NRMM models the vehicle/terrain interaction by analyzing the vehicle's maximum potential and the terrain's maximum potential and then merging these two together into a vehicle/terrain interaction (VTI) maximum potential. This VTI maximum potential includes the maximum tractive force the vehicle can generate with the terrain at near zero speed ("soil limited" tractive force), the maximum speed the vehicle can generate with the terrain, and the reserve tractive force available if traveling at any speed between zero and maximum.

The vehicle's maximum potential is modeled through the use of a tractive force - speed relation. This relation is based on the available torque versus rpm of the vehicle's power-train considered from the engine to the wheel (or track sprocket). The available torque is converted into tractive force and the rpm is converted into a translational speed in the absence of slip. The result is a "theoretical" tractive force versus speed relation.

The terrain's maximum potential is modeled through the use of many empirical relationships based on testing at WES since the early nineteen fifties. The primary purpose of these empirical relationships is to facilitate determination of the maximum tractive force a vehicle can obtain and the level of slip that will occur at any other level of tractive force when the vehicle interacts with a specific terrain. These are the empirical relationships under examination in this research.

The merging of these two potentials involves establishing a VTI tractive force - speed relation, usually referred to as the "soil corrected" tractive force - speed relation. The VTI tractive force - speed relation is first made equivalent to the vehicle's maximum potential. Then the zero-speed tractive force (maximum tractive force) for the vehicle is checked against the terrain's empirically demonstrated potential ("soil limited" tractive force) and reduced if necessary. Finally, speeds are reduced due to slip for the remaining usable tractive force - speed points (all those having tractive force less than the "soil limited"). This "soil corrected" tractive force - speed relation is used as the baseline for NRMM speed predictions.

Fundamental Origins of the Relationships

The NRMM II empirical relationships for predicting terrain potential are fundamentally based on a simple model of the traction element/terrain interaction. Figure 1 shows a typical tire/soil interaction with the resulting interaction stresses for a powered wheel interacting at a "steady state" speed (zero acceleration). The same basic analysis can be used for a tracked assembly. The inputs to the wheel from the axle are the wheel load (W_W), the torque (Q), and the drawbar pull (D)[1]. These input actions produce normal stresses and shearing stresses along the tire/soil interface.

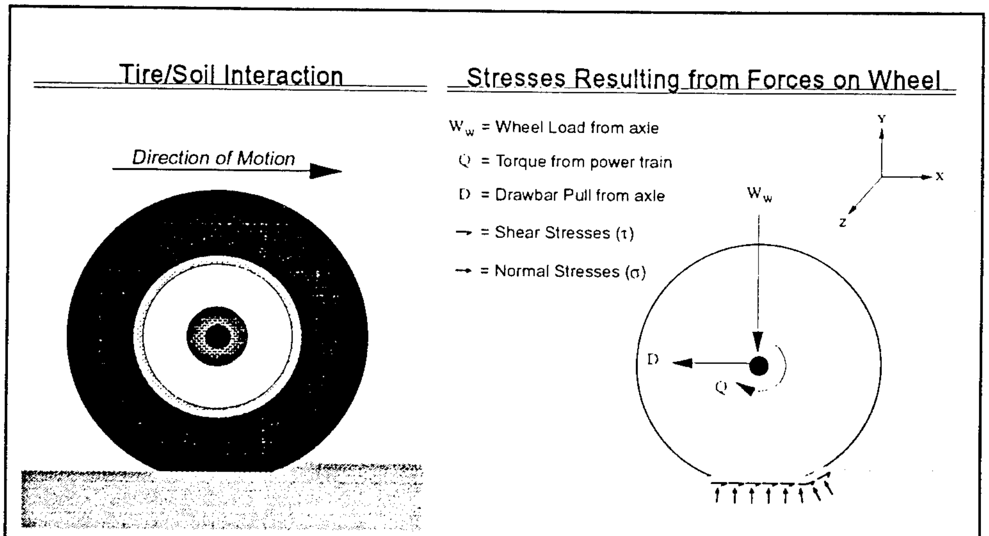


Figure 1. Tire/soil interaction and resulting interaction stresses

These stresses can be divided into horizontal and vertical components, and the components can then be converted into resultant horizontal and vertical forces at unique points along the interface. In the NRMM II simple stress analysis, all of the vertical stress components, normal and shearing,

[1] For convenience, the notation used throughout this report are listed at the end of Chapter 1.

are converted into a resultant vertical force (N), the horizontal normal stress components are converted into a resultant horizontal motion resisting force (R), and the horizontal shearing stress components are converted into a resultant horizontal tractive force (T) as shown below. These forc-

$$N = \sum_{j=1}^{NC} [(\sigma_{Y_j} + \tau_{Y_j}) A_{XZ}] \qquad R = \sum_{j=1}^{NC} [\sigma_{X_j} A_{YZ}] \qquad T = \sum_{j=1}^{NC} [\tau_{X_j} A_{XZ}]$$

es are shown at their unique points, designated by the force eccentricities, along the tire/soil interface in Figure 2. In the NRMM II method of predicting speed, the magnitude of the eccentricities is not needed, and hence the analysis is greatly simplified. It should be noted that at the element (or assembly) level, R is due to the deformable medium (soil) plus the internal rolling resistance of the traction elements.

In analysis of the freebody diagram, setting the sum of the horizontal forces equal to zero results in the tractive force (T) being equal to the sum of the drawbar pull (D) and the motion resistance (R) as below.

Tractive Force = Drawbar Pull + Motion Resistance

Setting the sum of the vertical forces on the wheel equal to zero results in N being equal to W_W. In further analysis of the freebody diagram, the assumption is made that the maximum producible tractive force (T_{MAX}) at the tire/soil interface is proportional to the normal force between the soil and tire, and the magnitude of T_{MAX} is assumed to be based on a coefficient of friction, μ. It is also assumed that the normal force for generating traction between the soil and tire can be considered equivalent to the resultant vertical force (N). With these assumptions, T_{MAX} is equal to the product of μ and W_W, or μ is as shown below.

$$\mu = \frac{T_{MAX}}{W_W}$$

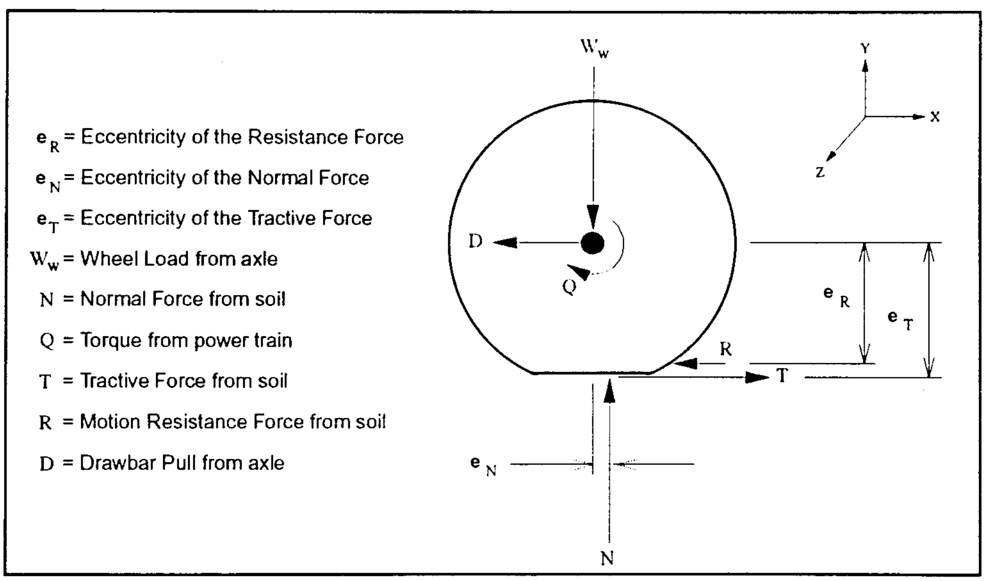


Figure 2. Freebody diagram of the NRMM II simple force analysis

In NRMM II, the cross-country traction empirical relationships are used to indirectly predict μ from which the "soil limited" tractive force (T_{Soil}) for a vehicle can be predicted. In NRMM II, μ represents the traction coefficient for a vehicle rather than a single element, and therefore is the ratio of T_{Soil} over GVW_P. The ideal situation would be to have empirical relationships for μ as a function of terrain and vehicle characteristics. To obtain this situation empirically, the T_{Soil} over GVW_P ratio would need to be measured for many different vehicles interacting with many different types of terrain. Unfortunately, this ideal situation was never achieved because T_{Soil} is extremely difficult, if not impossible, to measure, but the "soil limited" drawbar pull (D_{Soil}) and motion resistance can be measured. Therefore, since the sum of D_{Soil} and R is equal to T_{Soil}, relationships were empirically developed to predict drawbar pull and motion resistance. The only other parameter necessary to generate the "soil corrected" tractive force - speed relation is the slip. The cross-country traction empirical relationships are used to fill this need also, being used to directly predict slip.

Figure 3 shows the results of the element/terrain interaction analysis applied to a vehicle with an emphasis on active forces, reactive forces, and effects of the action/reaction interaction. Once again, the same basic actions and reactions shown in this figure could be applied to a tracked vehicle. Figure 3 shows that the vehicle activates the assembly/terrain interaction by transferring an assembly weight (W_i) and a tractive force (T_i) for each powered assembly. The terrain reacts by returning T_i and

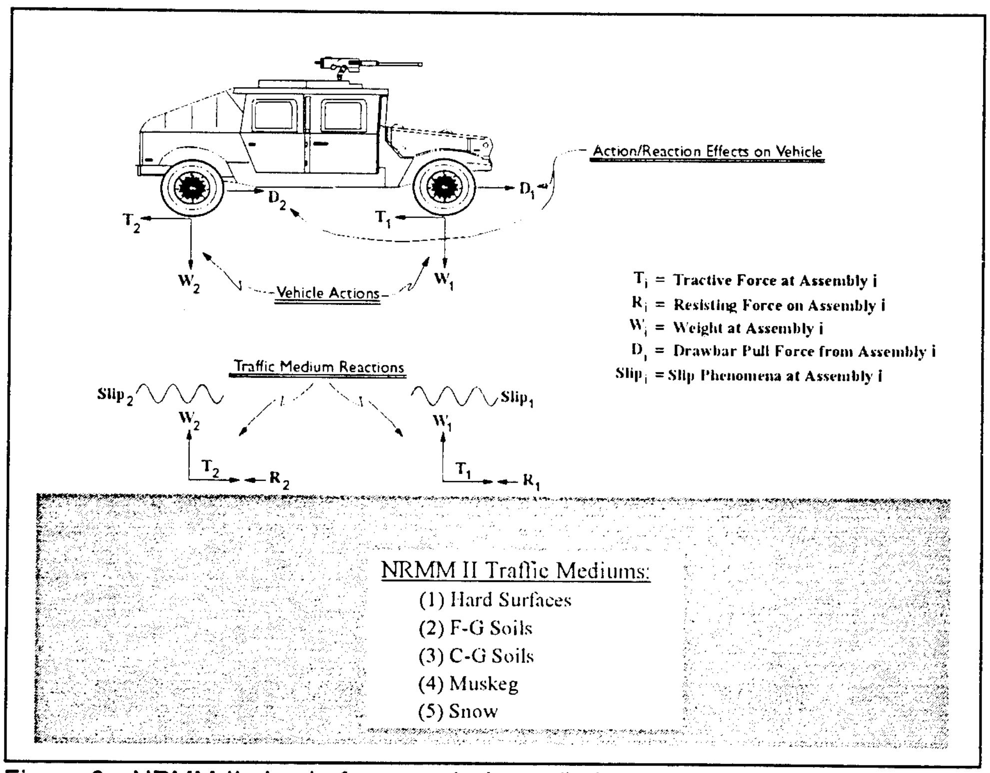


Figure 3. NRMM II simple force analysis applied to a vehicle

W_i but also by activating the motion resistance (R_i) and the slip ($Slip_i$) at each assembly/terrain interface. The resulting action/reaction effects on the vehicle are the drawbar pull forces (D_i) from each assembly. The drawbar pull forces are the forces that would accelerate the vehicle, but NRMM II is not concerned with accelerations, instead being concerned only with "steady-state" speeds. Therefore, NRMM II considers the drawbar pull forces as reserve tractive force, available for such things as pulling unpowered trailers, when the vehicle is traveling at some speed other than its maximum VTI potential. In the case where the vehicle is at the maximum VTI potential speed, the drawbar pull forces are equal to zero and the tractive forces become equal to the motion resisting forces.

Implemented Use of the Relationships

Three unique cross-country traction prediction methodologies are implemented in NRMM II: (1) the VCI_1 Methodology, (2) the Numeric Methodology, and (3) the Mohr-Coulomb (CRREL) Methodology. Each of these methodologies facilitates production of the "soil corrected" tractive force - speed relation by establishing two of the three traction modeling parameters:

(1) Drawbar Pull and
(2) Motion Resistance.

The third traction modeling parameter, slip, is established using the same approach regardless of the traction prediction methodology under use. Only the VCI_1 Methodology and the Numeric Methodology are examined under the scope of this report.

The VCI_1 Methodology evolved from field testing of standard, full-size vehicles in prepared and natural soil deposits. In this method, the vehicle is first evaluated alone based on several of its traction influencing characteristics. This evaluation results in the prediction of the VCI_1. Then the soil is figured in, and the result is an empirical parameter from which drawbar pull and motion resistance predictions can be made. The Numeric Methodology was developed from controlled laboratory testing of single traction elements (model and real) in prepared soil deposits. In this method, the vehicle and soil are evaluated together in one step, and hence the initial determination of the VCI_1 is not needed. The result is a dimensionless empirical parameter from which drawbar pull and motion resistance predictions can be made. The implemented use of the output drawbar pull and motion resistance from both methodologies is identical.

The following sections provide a more detailed discussion of the implemented use of the VCI_1, drawbar pull, slip, and motion resistance empirical relationships. A small discussion of the historical origins as well as the current implemented use is provided. The final section provides a detailed graphical overview of the NRMM II general traction prediction scheme.

One-Pass Vehicle Cone Index

The NRMM II VCI_1 relationships were empirically derived from multi-pass field tests with all-drive vehicles. The original purpose of the relationships was to predict the minimum level-terrain soil strength on which a vehicle could just make one pass without becoming immobilized. From this definition, it is apparent that VCI_1 is also the soil strength at which a vehicle's drawbar pull ability is zero. When the modeling focus shifted from identifying immobilization areas to predicting speed, the necessary modeling parameters were the drawbar pull, motion resistance, and slip. VCI_1 was not one of the necessary parameters, but it does fit into the prediction scheme.

The VCI_1 fits in because of an observation made at WES during the late nineteen sixties. WES researchers observed that many vehicles with common assembly characteristics could be placed into groups, and drawbar pull coefficient versus soil strength predictions could be made for all the vehicles in a group with one prediction curve. This could be accomplished by subtracting the VCI_1 from the actual soil strength magnitudes. This essentially shifts the drawbar versus soil strength performance curves for all vehicles to a common initial zero drawbar pull point, VCI_1. The resulting relative soil strengths in excess of VCI_1 upon which group drawbar pull predictions could be made was called the excess soil strength (SS_X). Since SS_X was to be a parameter for making drawbar pull predictions, VCI_1 had become another necessary modeling parameter in predicting speed.

The VCI_1 relationships are now used in NRMM II to predict VCI_1 for individual traction assemblies rather than vehicles. The assumption was made that the VCI_1 for an individual assembly is equivalent to the VCI_1 for the entire vehicle if all of the vehicle's assemblies are similar. The assembly VCI_1 values are used in NRMM II to predict drawbar pull and motion resistance for each individual assembly. The assembly VCI_1 values are also used in the Combination VCI Routine (VPP Routine II18) to establish the more familiar Vehicle VCI_1.

The Combination VCI Routine assumes a value of soil strength, and then it predicts D/W for powered assemblies and R/W for unpowered assemblies. The D/W for powered assemblies and the R/W for unpowered assemblies can be used to determine D for a vehicle as shown in Figure 4. Since the Vehicle VCI_1 represents the soil strength where a vehicle's D is equal to zero, the Combination VCI Routine uses an iterative method to determine the soil strength value that forces the predicted D of a vehicle to be equal to zero. This iteratively determined soil strength value is then termed the Vehicle VCI_1.

It should be noted that, in NRMM II, the Vehicle VCI_1 is computed primarily as a relative indicator of vehicle performance. It is not used to compute drawbar pull or motion resistance because, as stated above, these traction modeling parameters are now computed for each individual traction assembly. The Vehicle VCI_1 is currently only used in a small routine (AREAL Routine IV03) that decides which soil strength to use for computing SS_X, that for the 0-6 inch layer or the 6-12 inch layer. It serves no

$$D = \sum_{i=1}^{A_P} (T_{P_i}) - \sum_{i=1}^{A_P} (R_{P_i}) - \sum_{i=1}^{A_U} (R_{U_i})$$

and noting that $\sum_{i=1}^{A_P} (T_{P_i}) - \sum_{i=1}^{A_P} (R_{P_i}) = \sum_{i=1}^{A_P} (D_{P_i})$ *yields*

$D = \sum_{i=1}^{A_P} (D_{P_i}) - \sum_{i=1}^{A_U} (R_{U_i})$ *which can be evaluated in coefficient form as*

$$D = \sum_{i=1}^{A_P} \left[\left(\frac{D}{W}\right)_{P_i} W_{P_i} \right] - \sum_{i=1}^{A_U} \left[\left(\frac{R}{W}\right)_{U_i} W_{U_i} \right]$$

Figure 4. Vehicle drawbar pull computed using D/W for powered assemblies and R/W for unpowered assemblies

other purpose in predicting the ultimate goal of NRMM II, speed. It was important to mention in this report because predictions from the Combination VCI Routine can be directly compared with field measured Vehicle VCI_1 values for evaluating the variability in the entire VCI_1 prediction process.

Drawbar Pull Coefficient at Nominal Slip

The drawbar pull coefficient relationships were empirically derived from field tests with all-drive vehicles (VCI_1 Methodology) or from laboratory tests with single elements (Numeric Methodology) conducted from the nineteen sixties through the nineteen eighties. The original goal in developing drawbar pull relationships was to predict the maximum amount a vehicle could pull on level terrain or to approximate the maximum slope a vehicle could climb, at a given soil strength and a slow "steady state" speed. When the modeling focus shifted towards predicting maximum speed as a function of vehicle and terrain, the maximum tractive force, T_{Soil}, was a necessary modeling parameter. Since maximum drawbar pull was already under investigation, is simple to measure, and can be used to obtain maximum tractive force, drawbar pull became a necessary modeling parameter in predicting speed.

The relationships are now used to predict drawbar pull coefficient at nominal slip for each individual assembly. The assumption was made that each assembly on an all-drive vehicle would demonstrate a ratio of drawbar pull over assembly weight equivalent to the ratio of drawbar pull over vehicle weight demonstrated by the vehicle, provided that all of the assemblies are similar. The relationships are used on a per assembly basis so that speed can be predicted for vehicles that are not all-drive. In this more general case, only powered assemblies would contribute to the overall tractive force, and hence drawbar pull, generated by the vehicle.

Slip at "Maximum" Soil Strength

The slip relationships were empirically derived from field tests conducted with all-drive vehicles from the nineteen sixties through the nineteen eighties. One purpose of measuring slip as well as drawbar pull on a certain RCI was to determine the slip at which maximum drawbar pull efficiency was obtained. The magnitude of D at this optimum slip would be a better relative indicator of vehicle performance and useful tractive force than the absolute maximum D. It was also realized that these relationships derived for predicting D/W as a function of slip could also be used to predict the slip expected to occur when a vehicle was at a certain magnitude of D/W.

The empirical slip relationships are now used to predict both drawbar pull coefficients and slip for a vehicle (NOT per assembly). The relationships are considered to be indicators of the drawbar pull performance and the slip performance that would occur on "maximum" soil strengths. When predictions are to be made on soil strengths other than "maximum" soil strengths, the empirical relationships are shifted in such a way as to force higher slip predictions on lower soil strengths. This shift is done by evaluating the difference, Δ, between the drawbar pull coefficient at nominal slip and "maximum" soil strength and the drawbar pull coefficient at nominal slip and the other soil strength. Then the entire slip relationship is shifted by Δ in the D/W direction. The modeling hypothesis is that the value of Δ observed at nominal slip would be the same for any other slip.

"Maximum" soil strength is an average soil strength characteristic of a data set used to develop a specific slip relationship. The "maximum" soil strength value varies from one relationship to another depending on the range and magnitude of soil strengths used to empirically establish the relationship's prediction equation(s). The actual value of "maximum" is not necessary information for NRMM predictions. This is true because of the way NRMM shifts the slip relationship to the appropriate soil strength condition for each particular prediction. Historically, slip relationships were developed so that they would truly represent a maximum soil strength condition (hence the term Slip at "Maximum" Soil Strength), but this is not necessary, nor is it true for all of the relationships. The only thing important for NRMM is that the general shape of the slip relationships and the actual magnitude and shape of the Drawbar Pull Coefficient at Nominal Slip relationships be empirically correct. Perhaps the slip relationships would be better termed the Slip at "Nominal" Soil Strength relationships where "nominal" represents the soil strength where empirical data are abundant.

Motion Resistance Coefficient

The motion resistance coefficient relationships were empirically derived from field tests with all-drive vehicles (VCI_1 Methodology) or from laboratory tests with single elements (Numeric Methodology) conducted from the nineteen sixties through the nineteen eighties. The purpose of the relationships was to predict the rolling resistance force opposing the motion of a vehicle during interaction with a given terrain soil strength. Only rolling resistance motion resistance forces were considered because traction is produced at the element level. Other motion resistance forces such as air drag are at the vehicle level, and they are considered in NRMM II outside of the traction prediction scheme. The motion resistance coefficient relationships were established because motion resistance force as a function of vehicle and terrain was a necessary modeling parameter in predicting speed.

The relationships are now used to predict motion resistance coefficient for each individual assembly. The relationships are used on a per assembly basis so that speed can be predicted for vehicles that are not all-drive. The assumption was made that each assembly on an all-drive vehicle would incur a ratio of motion resistance over assembly weight equivalent to the ratio of motion resistance over vehicle weight incurred by the vehicle. This assumption was made with the knowledge that most of the vehicles upon which the empirical R/W relationships were based only had two or three assemblies. A second assumption was that unpowered wheeled assemblies would incur a slightly different ratio of motion resistance over assembly weight than powered wheeled assemblies. Contrarily, it was assumed that tracked assemblies would incur the same ratio of motion resistance over assembly weight regardless of whether it was powered or unpowered.

Implementation Overview

To fully understand how the empirical relationships are used in NRMM II and how the internal scatter in each relationship propagates throughout a model speed prediction, words are informative but inadequate. For this reason, Figures 5 and 6 are employed for a general, visual overview. These two figures in combination show the ways in which the cross-country traction empirical modeling parameters just described are used in NRMM II.

Figure 5 is a general computational flowchart that demonstrates the roles of the empirical relationships in obtaining the "soil corrected" tractive force - speed relation. The empirical relationships are the functions in the thick-lined rectangular boxes. The figure does **not** represent a flowchart of the NRMM II program source code, although it would closely resemble that type of flowchart. Instead, the figure represents a flowchart of the major computational steps that would have to be taken if the process were to be done manually ("by hand"). Each of the rectangular boxes represents a particular computational step that is done in NRMM II, but the portions of the computations not necessary for this discussion are left out, i.e. minor steps and parts of the automated computations are not shown. Each of the major steps are numbered so that following the progression of the discussion through the flowchart is easier.

Steps (1) and (2) of Figure 5 show that D/W and R/W are computed as functions of the general parameter, λ, for each powered assembly. D/W

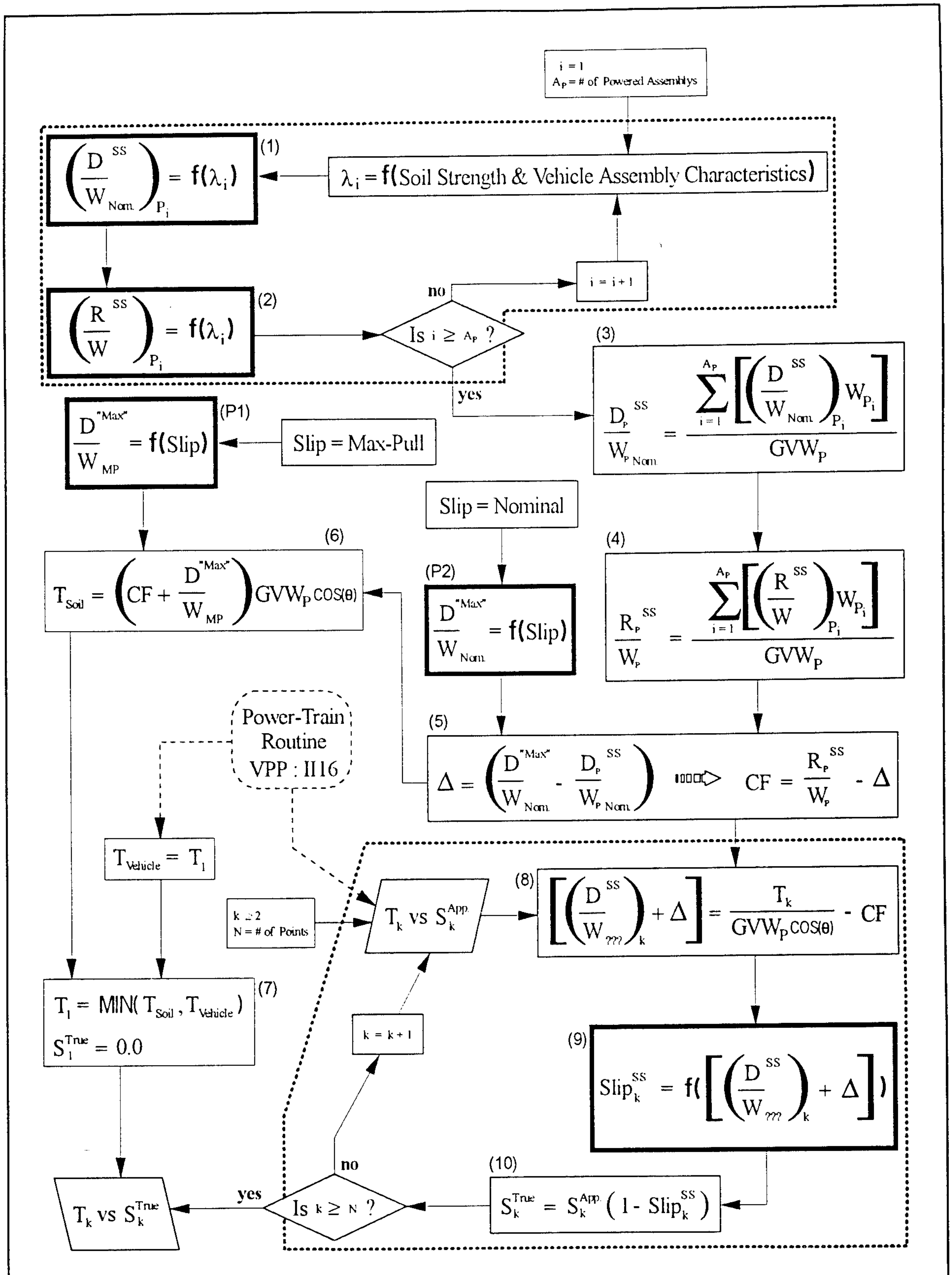


Figure 5. General computational flowchart for NRMM II cross-country traction predictions (selective parts of NRMM II: AREAL: Routines IV3, IV4, and IV5)

is at nominal slip and is computed using the empirical Drawbar at Nominal Slip relationships, and R/W is computed using the empirical Motion Resistance relationships. Both D/W and R/W are based on the particular terrain soil strength. λ is a function of terrain soil strength and vehicle assembly characteristics, and it is a chameleon parameter in that **D/W predictions are not necessarily made with the same parameter as R/W predictions**. The powered assembly D/W and R/W values are then summed into partial-vehicle D/W and R/W values in steps (3) and (4). These partial-vehicle values represent the D/W at nominal slip and SS and the R/W at SS, both being only for the powered assemblies. Prior to obtaining the partial-vehicle values, two D/W values are computed using the empirical Slip at "Maximum" Soil Strength relationships as shown in steps (P1) and (P2). The first of these D/W values is based on maximum-pull slip (not always 100%), the second is based on nominal slip, and both are based on "maximum" soil strength. At this point, the computations branch into two major roles.

The first role is to compute the zero-speed tractive force for the tractive force - speed relation, i.e. the first point on the "soil corrected" tractive force - speed curve. The computational steps involved are steps (5), (6) and (7). First, all four of the empirical force coefficients, three drawbar and one motion resistance, are used to compute the "soil limited" tractive force (T_{Soil}). Step (5) is shown as two sub-steps so that the Δ shift term is pointed out, though the step is actually done in NRMM II with one computation. The CF term represents a correction factor used in NRMM II to convert drawbar pull coefficients to tractive force coefficients and vice versa. The computations in steps (5) and (6) amount to computing T_{Soil} as shown below. This shows that the D/W at nominal slip and SS is shifted up to the D/W at maximum-pull slip and SS based on the empirically demonstrated difference obtained from the Slip at "Maximum" Soil Strength relationship. Then the R/W at SS is added to obtain the maximum tractive force coefficient at SS which represents the desired coefficient of friction μ. The maximum tractive force the vehicle can generate on the terrain is finally obtained by multiplying μ by the normal force, $GVW_P COS(\theta)$, where θ is the slope angle of inclination.

$$T_{Soil} = \left[\frac{D_P}{W_{P_{Nom.}}}^{SS} + \left(\frac{D}{W}_{MP}^{"Max"} - \frac{D}{W}_{Nom.}^{"Max"} \right) + \frac{R_P}{W_P}^{SS} \right] GVW_P COS(\theta)$$

This value of T_{Soil} will then be compared, in step (7), to the zero-speed tractive force that the vehicle can develop in the absence of slip, $T_{Vehicle}$, as supplied by the Power-Train Routine. For the majority of vehicles, T_{Soil} will be the minimum of these two, but this check is made for the case when a vehicle is underpowered. If T_{Soil} does control, i.e. is minimum, then the Power-Train supplied tractive force speed points for which the tractive force is greater than T_{Soil} will be omitted, and $(0,T_{Soil})$ becomes the first point on the "soil corrected" tractive force - speed curve.

The second role is to correct the vehicle speed for all of the remaining useable tractive force - speed points (all those having tractive force less than the "soil limited"). The computational steps involved, as shown in Figure 5, are (5), (8), (9), and (10). First, CF is obtained in step (5). Then the tractive force values are converted, in step (8), to drawbar pull coefficients at unknown slip and SS by dividing each T by the normal force, $GVW_pCOS(\theta)$, to obtain a traction coefficient and then subtracting the R/W at soil strength. In step (9), the slip is predicted from each of these drawbar pull coefficients using the shifted empirical Slip at "Maximum" Soil Strength relationship. The slip relationship is shifted using the shift constant Δ which essentially shifts the relationship from its natural "maximum" soil strength D/W magnitude to the SS D/W magnitude (the slip curve is shifted in the D/W direction). Finally, the vehicle speed is reduced from the apparent, or "theoretical", speed ($S^{App.}$) to the "soil corrected" vehicle speed (S^{True}) by using the computed slip as shown in step (10). This completes the remainder of the "soil corrected" tractive force - speed relation.

Figure 6 is an example of a "soil corrected" tractive force versus speed relation, and it demonstrates the final way in which the cross-country traction empirical relationships are used in NRMM II. Figure 6 graphically shows a typical "theoretical" tractive force - speed curve with the "soil corrected" version of the curve. Once this "soil corrected" tractive force - speed curve is obtained, the summation of the soil related rolling resistance forces for all of the vehicle's powered and unpowered assemblies are essentially superimposed onto the curve. The soil related rolling resistance forces are obtained by computing the motion resistance coefficients using the appropriate empirical relationships and then multiplying each coefficient by its assembly weight. These soil related rolling resistance forces are assumed to be constant with speed (not a function of speed), and therefore, the sum of these resistance forces is drawn in Figure 6 as a horizontal line. The "soil limited" maximum speed occurs at the intersection of this horizontal line and the "soil corrected" tractive force speed curve. The actual force controlled maximum speed will typically be less than the "soil limited" maximum speed since, as shown in Figure 6, there are usually more motion resisting forces involved (at the vehicle level).

Identity of the Relationships

NRMM II cross-country traction predictions for maximum vehicle/terrain potential can be divided into five major vehicle/terrain interaction (VTI) categories based on vehicle type and terrain type as follows:

(1) Vehicles on Fine-Grained Soils (includes Moist Sands with Fines),
(2) Tracked Vehicles on Coarse-Grained Soils (Arid Sands),
(3) Wheeled Vehicles on Coarse-Grained Soils (Arid Sands),
(4) Vehicles on Muskeg, and
(5) Vehicles on Snow.

The empirical relationships used for the first four of these VTI categories are identified in the following sections. The fifth VTI category is not part

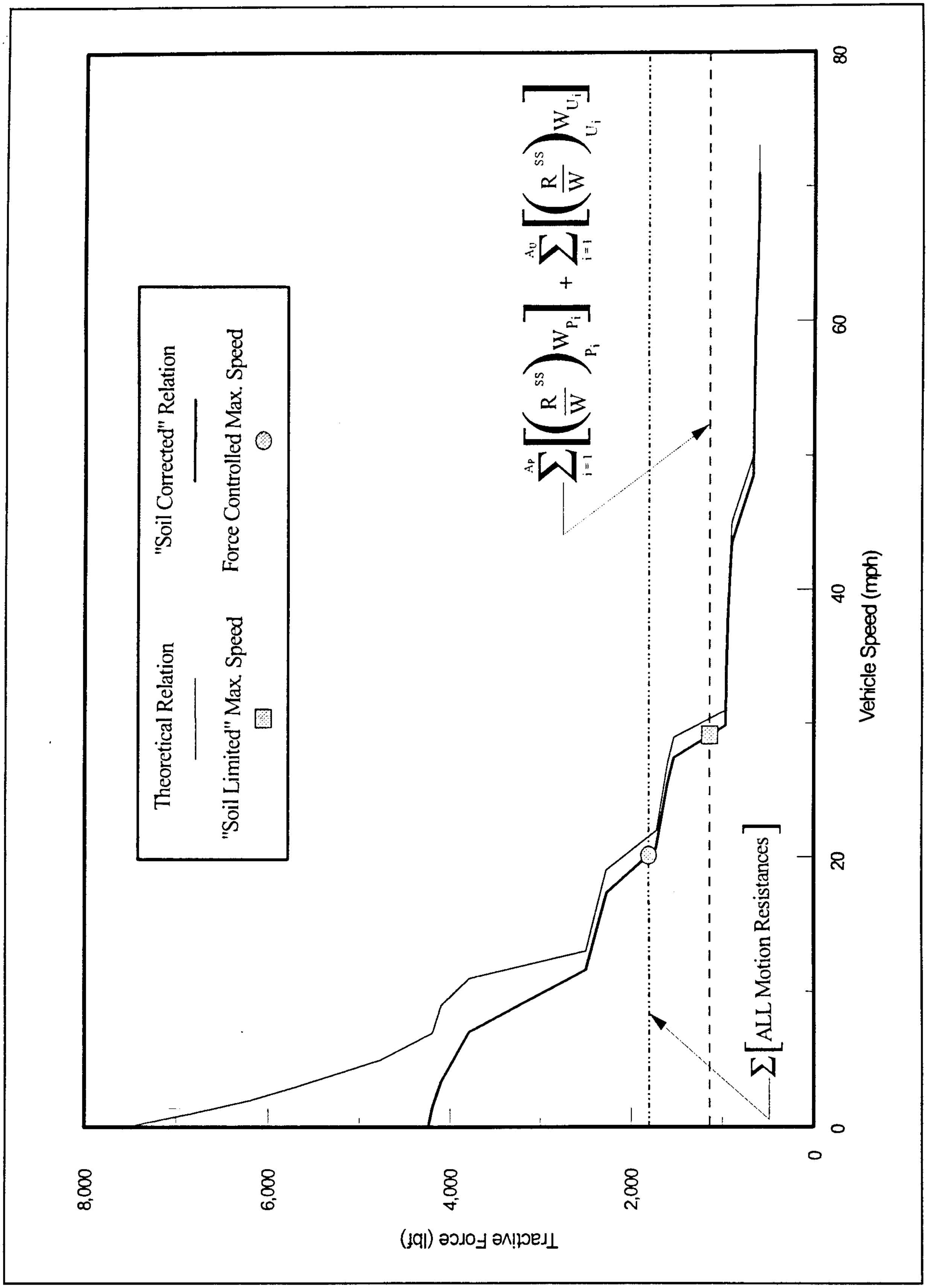


Figure 6. Typical "soil corrected" tractive force versus speed relation

of the scope of this report. Prior to the VTI category discussions, the basic format of and some helpful information about the tables containing the relationships is provided.

Relationship Table Format & "Need-to-Know" Information

Tables 1 through 11 all contain NRMM II empirical relationships, and they all follow the same basic semi-tabular format. They all contain relationship criteria, relationship names, and relationship prediction equations. The format requires that the tables be read from the left to the right with a funneling effect that leads eventually to the relationship name and prediction equation(s).

The criteria represent the NRMM II logic requirements for use of a particular relationship or equation, and they are implemented in the source code typically in the form of IF statements. The criteria, such as CPF and USCS soil type, are presented in a funneling down format rather than a true tabular format, and therefore, some of the criteria shown for one relationship are not necessarily shown for all of the other relationships. For example, in Table 3, the criteria for ER01 are wheeled, without tire chains, CPF $\geq$ 4 psi, SM soils whereas the criteria for ER04 are simply wheeled, with tire chains. It should also be noted that for some of the relationships, the vehicle related criteria represent vehicle characteristics whereas in other relationships they represent assembly characteristics. This depends on the implemented use of the relationships.

The relationship names were assigned for ease of reference only. They represent unique relationships, not unique equations. Therefore, some of the relationship names represent relationships for which predictions are made with more than one equation. For example, the Fine-Grained One-Pass Vehicle Cone Index relationship (Table 1) for wheeled, powered or braked is one relationship named VCI1FGW1, but two equations, one for MI $\leq$ 115 psi and one for MI > 115 psi, are used for predictions. The names were set up over an extended period of time; therefore, not all have logical characters.

The relationship prediction equations presented are only the empirically derived equations. There are other equations used to make predictions for some of the relationships in particular instances. The Drawbar at Nominal Slip and the Motion Resistance relationships used with the VCI_1 Methodology are examples. When these relationships were implemented for use with individual traction assemblies, a unique problem was created. The situation could occur where a vehicle's SS_X was positive, but one of the individual assemblies' SS_X was negative. Since no empirical data (vehicle data) would realistically involve negative SS_X, some hypothesis had to be made for the behavior of these relationships in the negative SS_X range, and equations were implemented for this condition. These equations are purely hypothetical and therefore, were not addressed in this study nor presented in the relationship tables.

One other thing to note concerns the Slip at "Maximum" Soil Strength relationships. The relationship equations are typically derived for D/W as a function of slip using asymptotic or parabolic equations. When these equations are converted into equations for slip as a function of D/W, they are only applicable for D/W values less than those that produces maximum-pull slip (defined for each of the VTI categories in the sections that follow). If a D/W value greater than the D/W at maximum-pull slip is used to compute slip with these relationships, nonsense results will be obtained. The magnitude of the applicable D/W at maximum-pull slip can be obtained by using the equations to solve for D/W as a function of slip with the slip set equal to maximum-pull slip. NRMM does this as a check before using the relationships, and if the D/W value to be put into the equation is too large, the predicted slip is set equal to maximum-pull slip.

Vehicles on Fine-Grained Soils

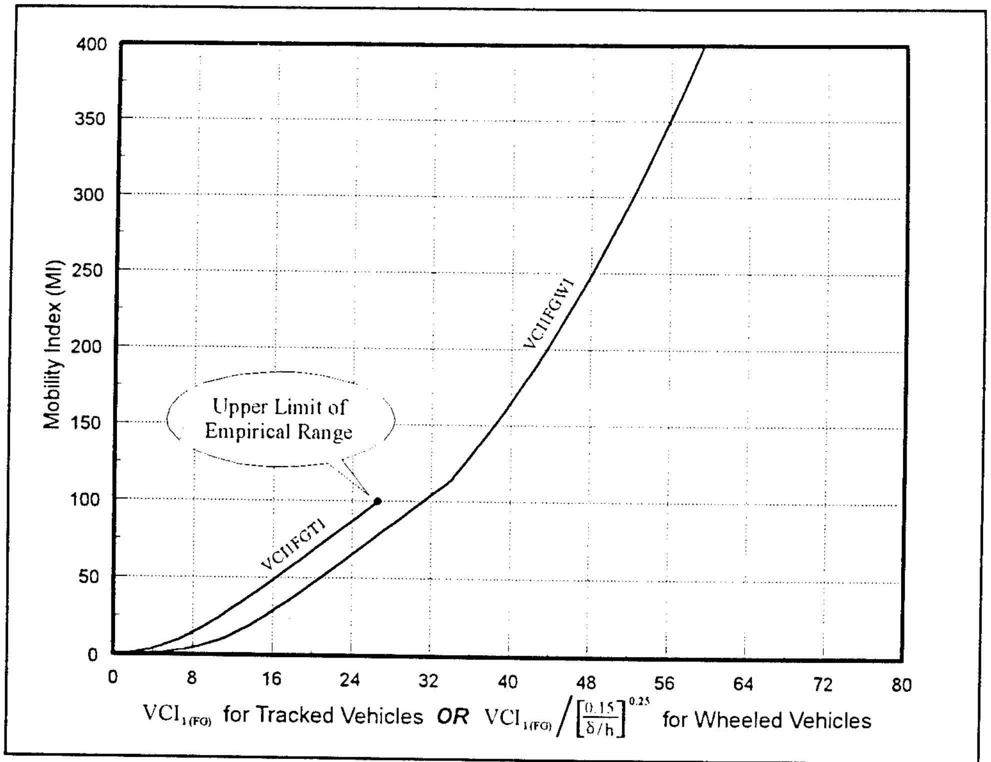
NRMM II models vehicle traction on fine-grained soils using the VCI_1 Methodology. The vehicle influence is accounted for through use of the Mobility Index (MI). MI is used to empirically predict the fine-grained one-pass vehicle cone index ($VCI_{1(FG)}$). The terrain influence is accounted for with the Rating Cone Index (RCI) measure of soil strength. The λ term is RCI_X for both D/W and R/W predictions, where RCI_X equals RCI minus $VCI_{1(FG)}$. Nominal slip and maximum-pull slip are both 100%. The following four traction modeling parameters are used to obtain the "soil corrected" tractive force - speed relation:

(1) Fine-Grained One-Pass Vehicle Cone Index (Table 1),
(2) Fine-Grained Drawbar at Nominal Slip (Table 3),
(3) Fine-Grained Slip at "Maximum" SS (Tables 4-5), and
(4) Fine-Grained Motion Resistance (Tables 6-7).

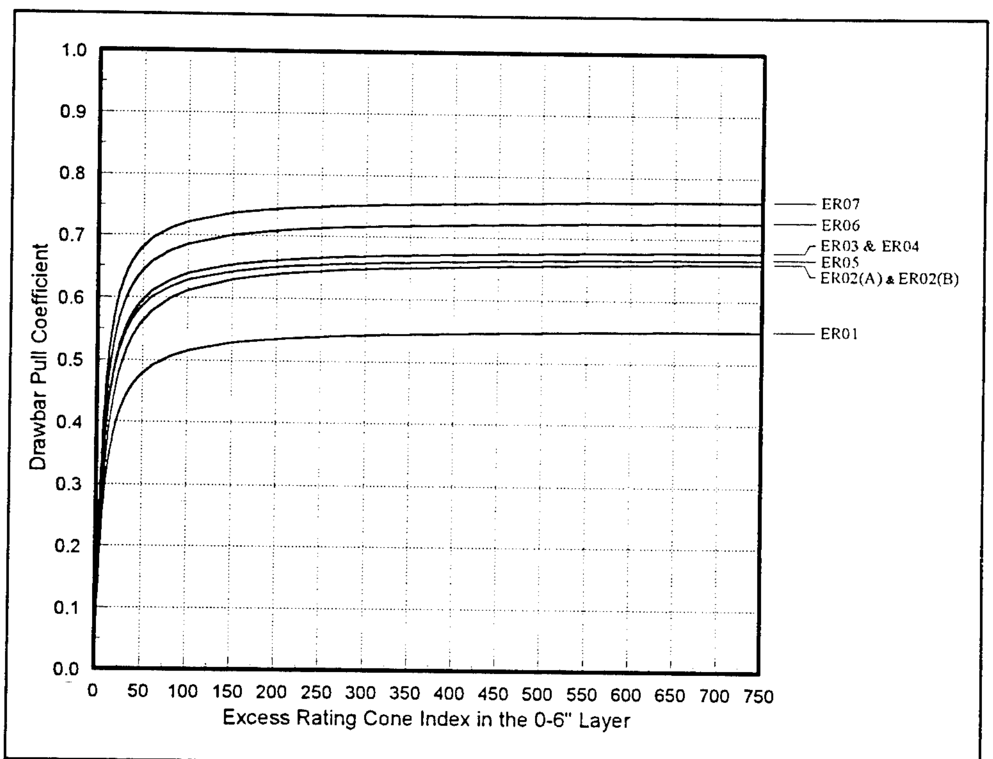
Tables 1 and 3 through 7 contain the empirical relationships used for each of these fine-grained traction modeling parameters. Figure 7 presents a graphical view of the families of prediction curves.

Nominal slip used to be 20%, and the word *nominal* was employed then because 20% represents a desirable slip condition, i.e. high traction efficiency and high traction. Nominal was changed to 100% (i.e. maximum-pull) in order to make Vehicle VCI_1 predictions represent an extremely difficult GO (borderline NOGO) rather than a relatively good GO (recall that Drawbar at Nominal Slip relationships are now used in predicting Vehicle VCI_1 in the Combination VCI Routine). Therefore, the word *nominal* now only represents the slip at which the Drawbar at Nominal Slip relationships are empirically based.

The USCS soil type criteria shown in Tables 3 through 7 and 11 represent the soil types on which nearly all of the empirical data are based, but each of these soil types is only a representative from a group of soil types, shown in Table 2, for which a particular relationship is used in predictions. In other words, predictions are made for interaction with all of the USCS soil types shown in one or more of the five soil groups using the empirical relationship derived from testing on the representative member, or members, of that particular soil group or groups. For example, if

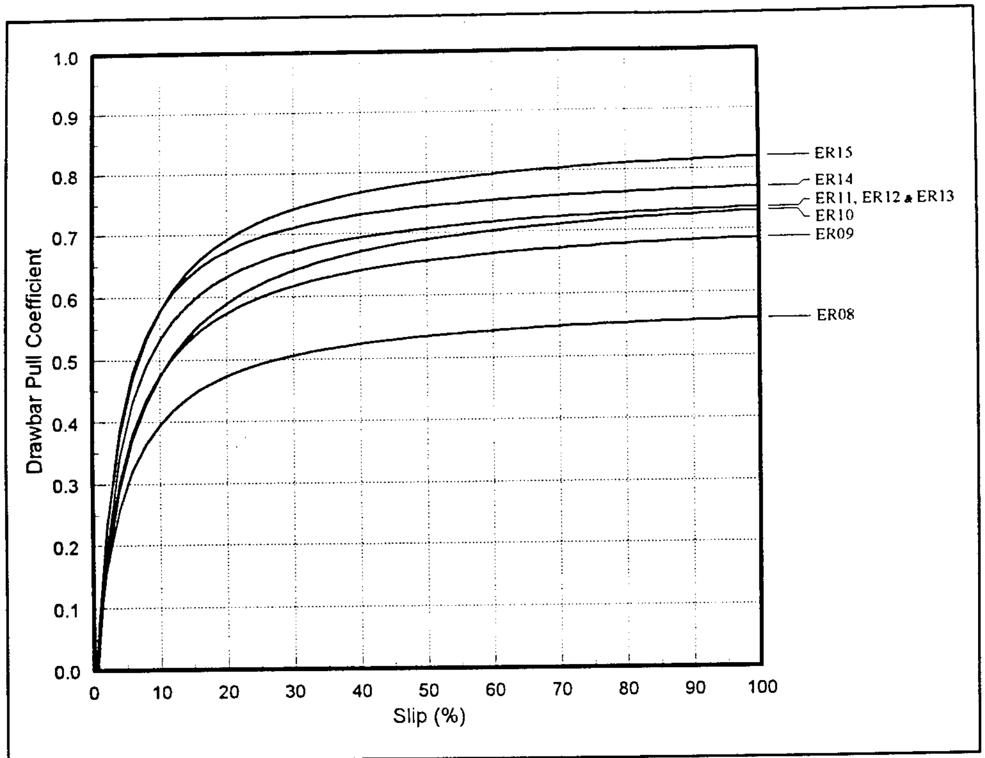


a. One-Pass Vehicle Cone Index for all assemblies

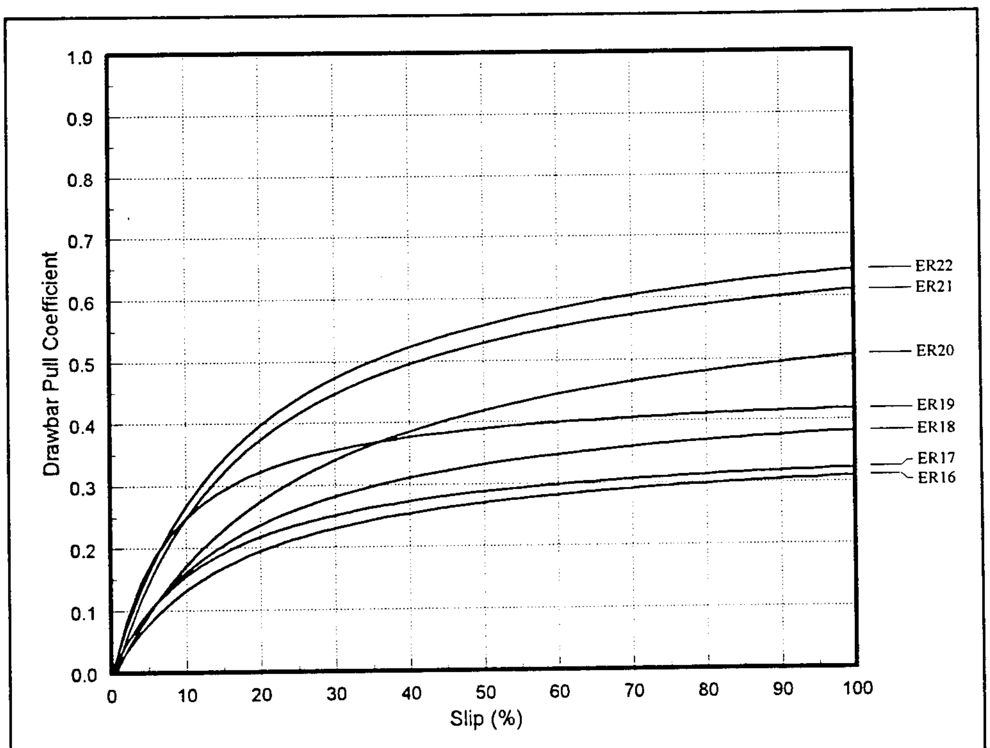


b. Drawbar at Nominal Slip for all assemblies

Figure 7. Families of prediction curves for vehicle traction on fine-grained soils (Continued)

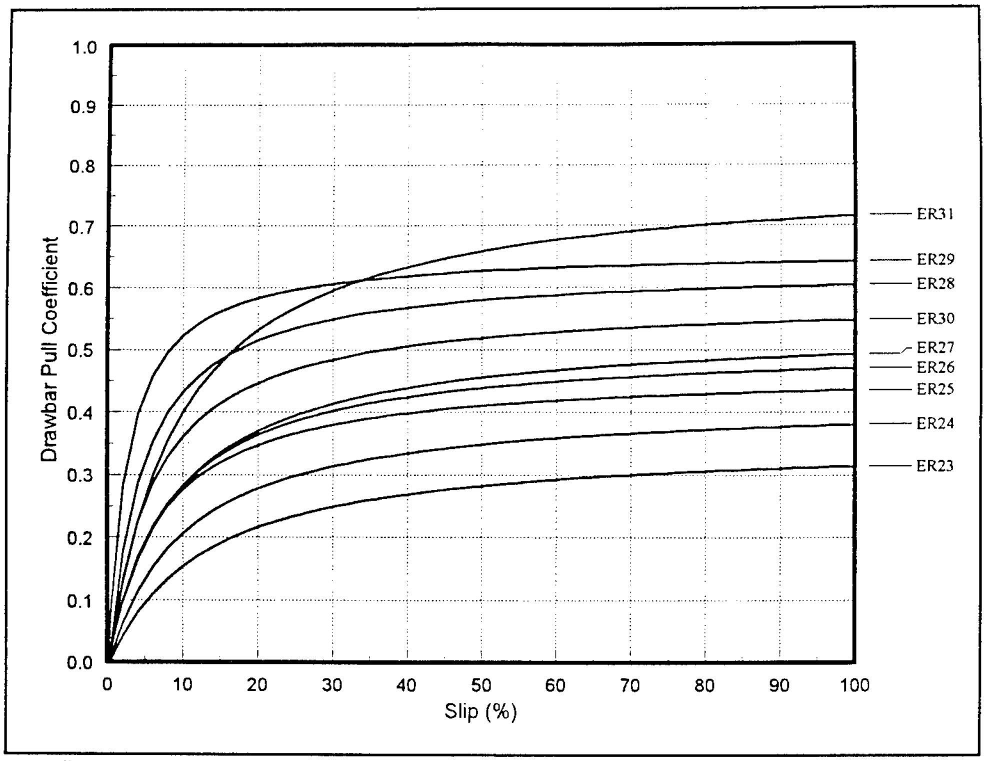


c. Slip at "Maximum" Soil Strength for all vehicles on non-slippery surface conditions

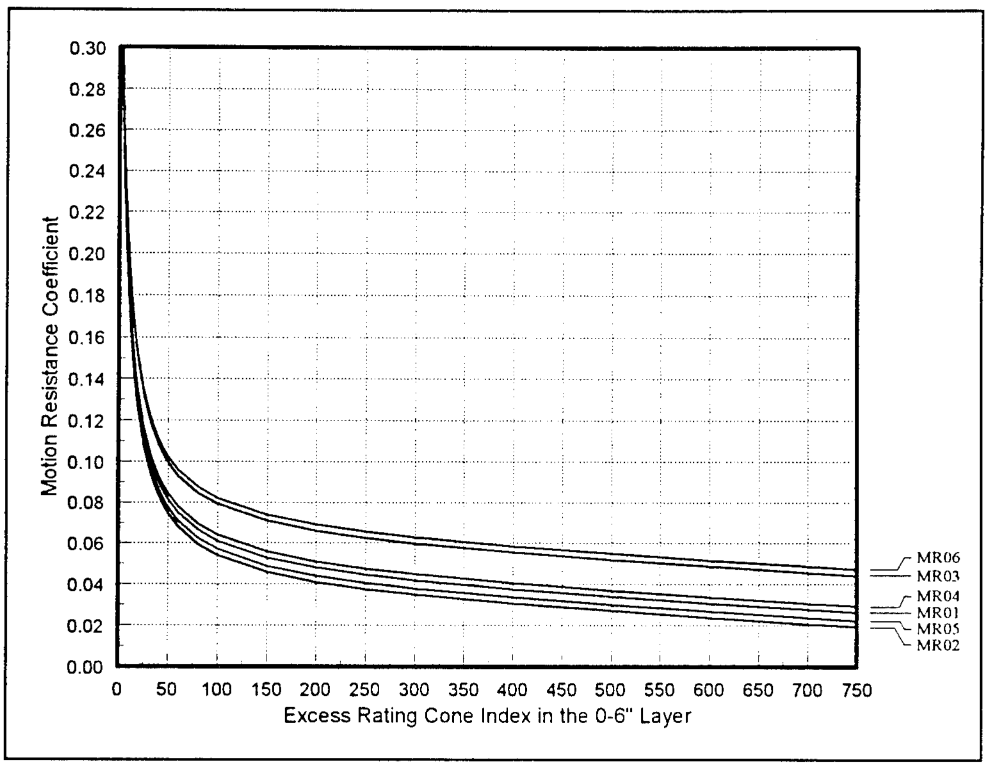


d. Slip at "Maximum" Soil Strength for wheeled vehicles on slippery surface conditions

Figure 7. (Continued)

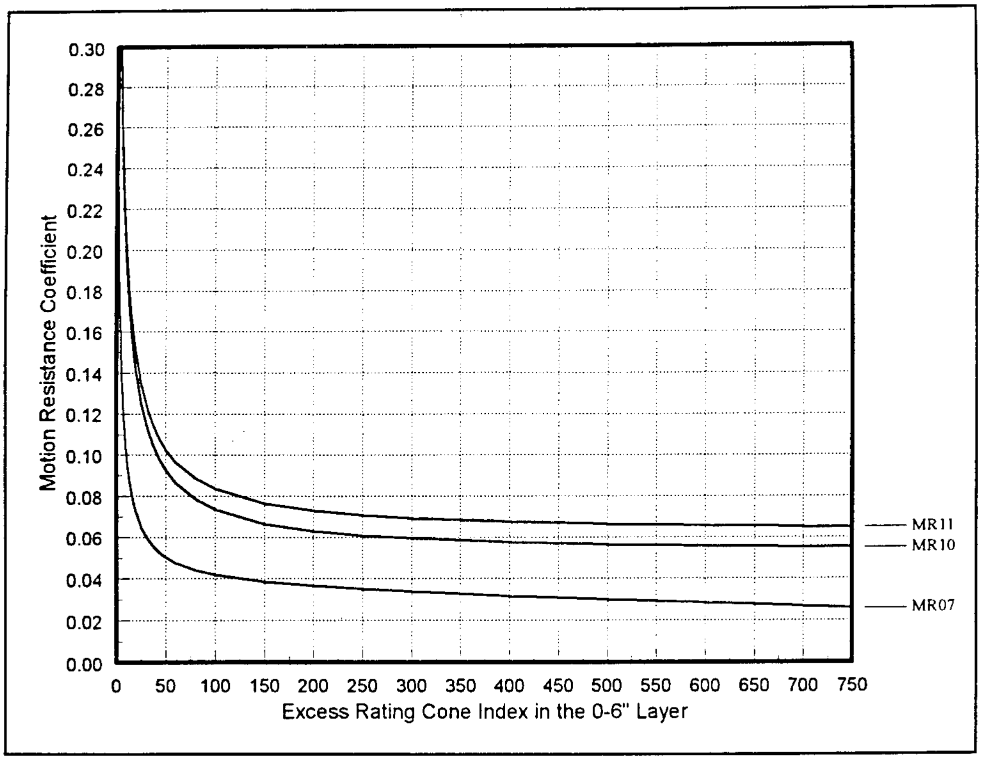


e. Slip at "Maximum" Soil Strength for tracked vehicles on slippery surface conditions

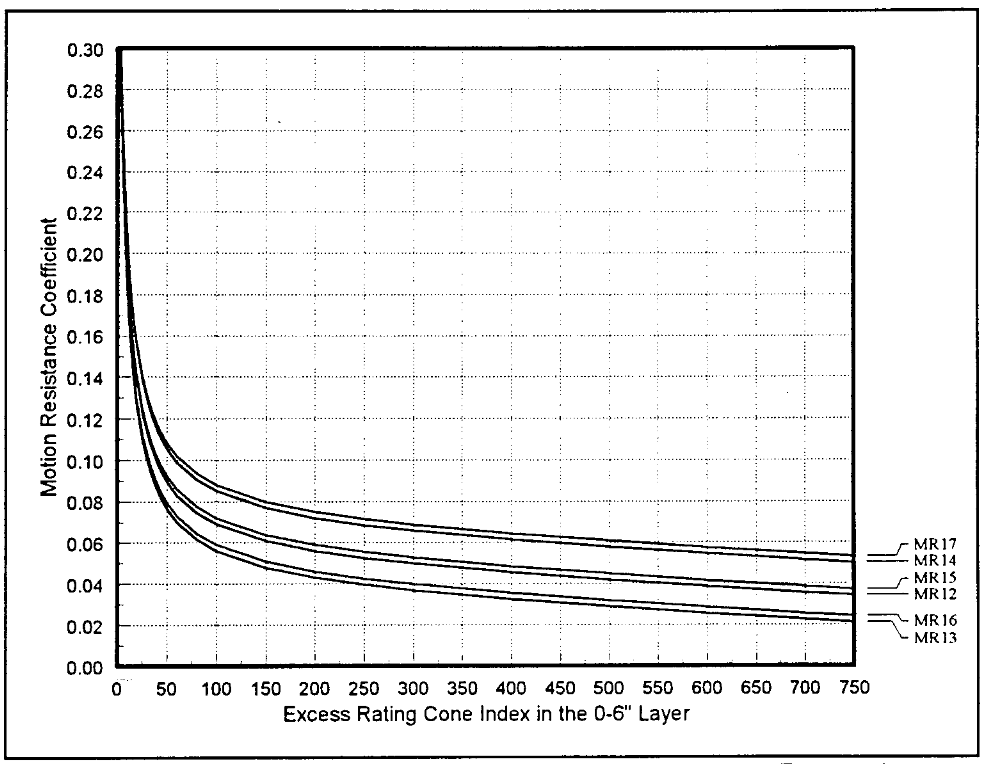


f. Motion Resistance for powered wheeled assemblies with CPF ≥ 4 psi on non-slippery surface conditions

Figure 7. (Continued)

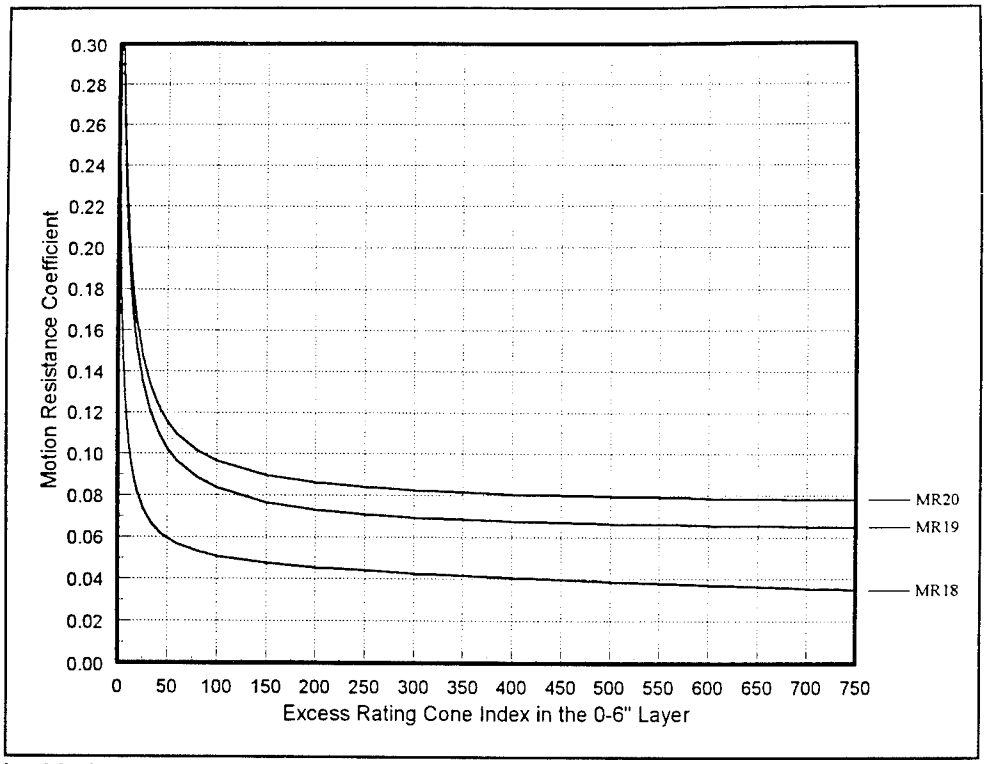


g. Motion Resistance for powered wheeled assemblies with CPF < 4 psi and all tracked assemblies on non-slippery surface conditions

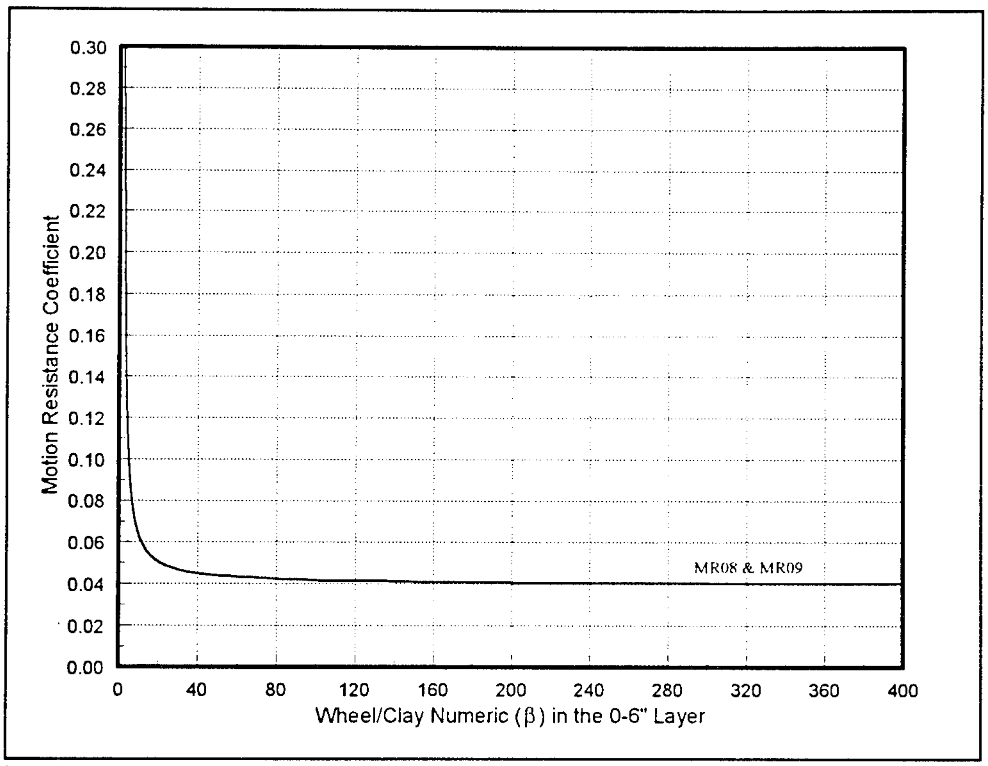


h. Motion Resistance for powered wheeled assemblies with CPF ≥ 4 psi on slippery surface conditions

Figure 7. (Continued)



i. Motion Resistance for powered wheeled assemblies with CPF < 4 psi and all tracked assemblies on slippery surface conditions



j. Motion Resistance for unpowered wheeled assemblies on all surface conditions

Figure 7. (Concluded)

a table's criteria show that a relationship was derived from testing on primarily SC and CH soil types, then that relationship would be used for predictions involving all of the USCS soil types in Soil Groups 1 and 2 shown in Table 2. If no USCS soil type is shown, the relationship is used for all of the Soil Groups. These soil groups were hypothesized based on the common characteristics of the soil types related to trafficability.

Tracked Vehicles on Coarse-Grained Soils

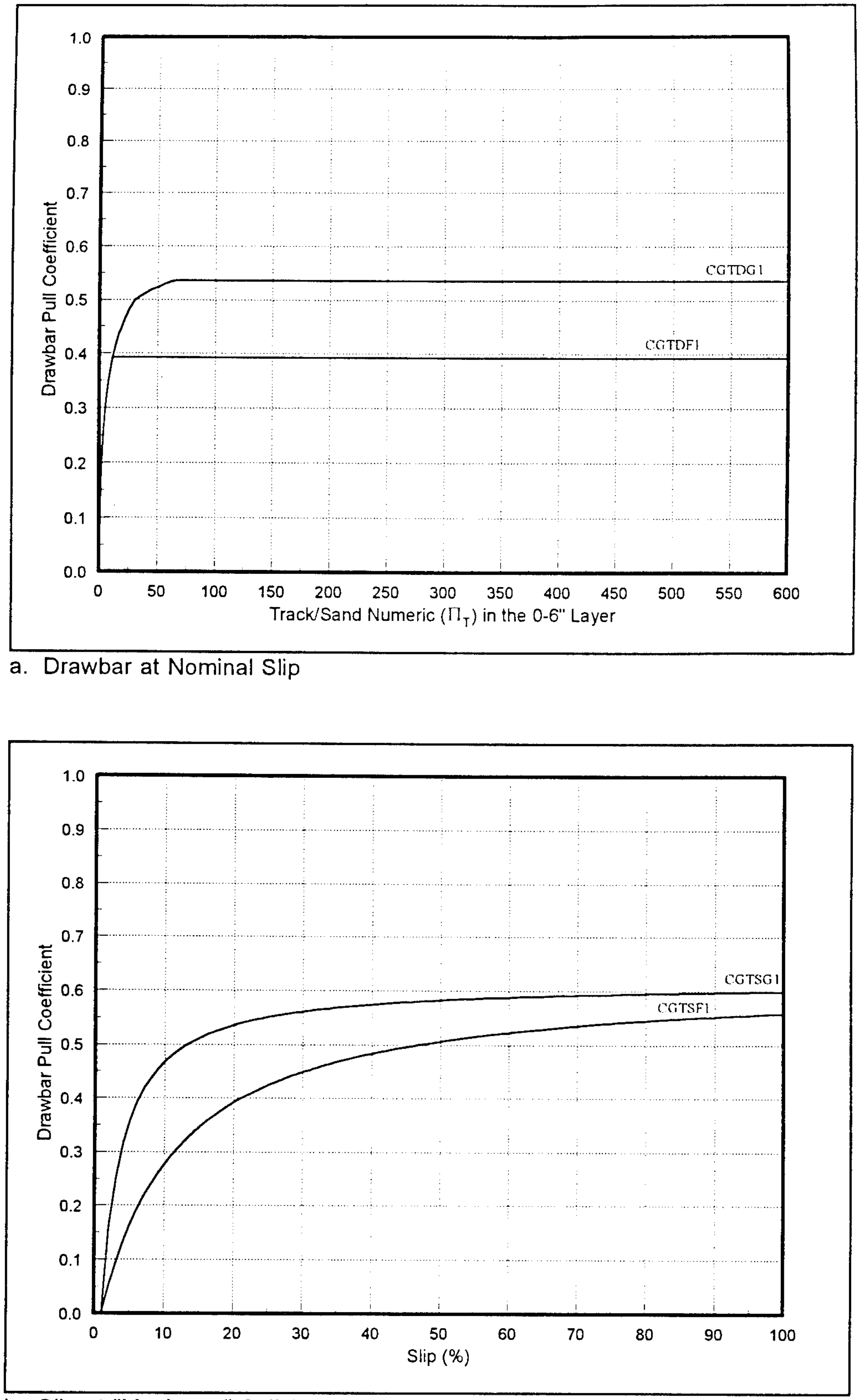
NRMM II models tracked vehicle traction on coarse-grained soils using the Numeric Methodology. The λ term for D/W predictions is the track/sand numeric (Π_T). Π_T is a dimensionless parameter composed of traction influencing vehicle characteristics and terrain characteristics. There is no λ term for R/W predictions because these relationships are constants. The terrain influence is accounted for with the Cone Index (CI) measure of soil strength. Nominal slip is 20%, and maximum-pull slip is 100%. The following three traction modeling parameters are used to obtain the "soil corrected" tractive force - speed relation:

(1) Tracked Drawbar at Nominal Slip on Coarse-Grained Soils,
(2) Tracked SLIP at "Maximum" SS on Coarse-Grained Soils, and
(3) Tracked Motion Resistance on Coarse-Grained Soils.

The relationships for these parameters are presented in Table 8. Figure 8 presents a graphical view of the families of prediction curves.

Π_T was developed from controlled laboratory testing with a single model track in an attempt to obtain a single numeric from which all necessary tracked modeling performance parameters could be evaluated. It worked well with the controlled model track data, but the data collected in the field demonstrated that Π_T was typically not needed for predicting tracked vehicle performance in sand because of the simplicity of the interaction. The field data demonstrated that tracked drawbar and tracked motion resistance in sand could be adequately modeled as constants with varying soil strength (CI) for typical tracked vehicles (Kennedy 1974). Therefore, Π_T is only used for a minor role and only in drawbar predictions.

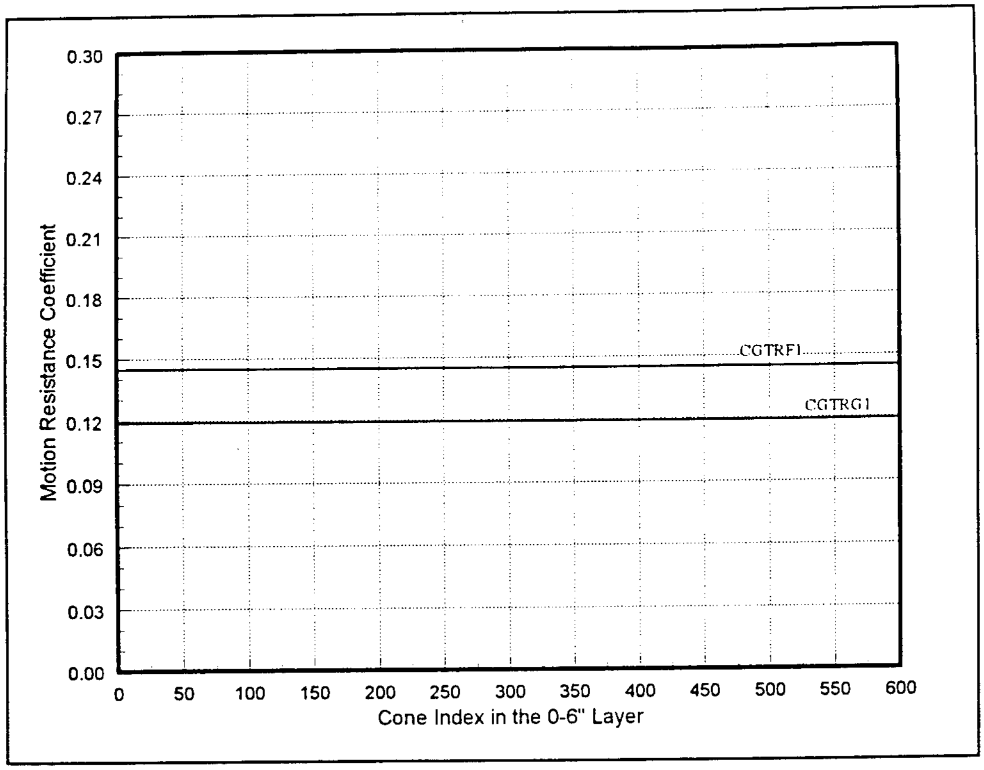
The D/W is first set equal to an empirical relationship based on Π_T. Then the D/W computed based on Π_T is compared to a constant cutoff D/W, and reduced to match the constant cutoff if necessary. Figure 9 graphically presents the way in which the track/sand numeric is used in making D/W predictions. The empirical D/W as a function of Π_T curve is shown with the two constant cutoffs. It should be noted that for any modern flexible tracked vehicle interacting with sand in the typical soil strength range ($30 < CI < 200$), the track/sand numeric relationship will probably never be used in an NRMM speed prediction because the cutoffs will always control. It should also be noted, though, that for a concept tracked vehicle system, the track/sand numeric could become a useful tool.



a. Drawbar at Nominal Slip

b. Slip at "Maximum" Soil Strength

Figure 8. Families of prediction curves for tracked vehicle traction on coarse-grained soils (Continued)



c. Motion Resistance

Figure 8. (Concluded)

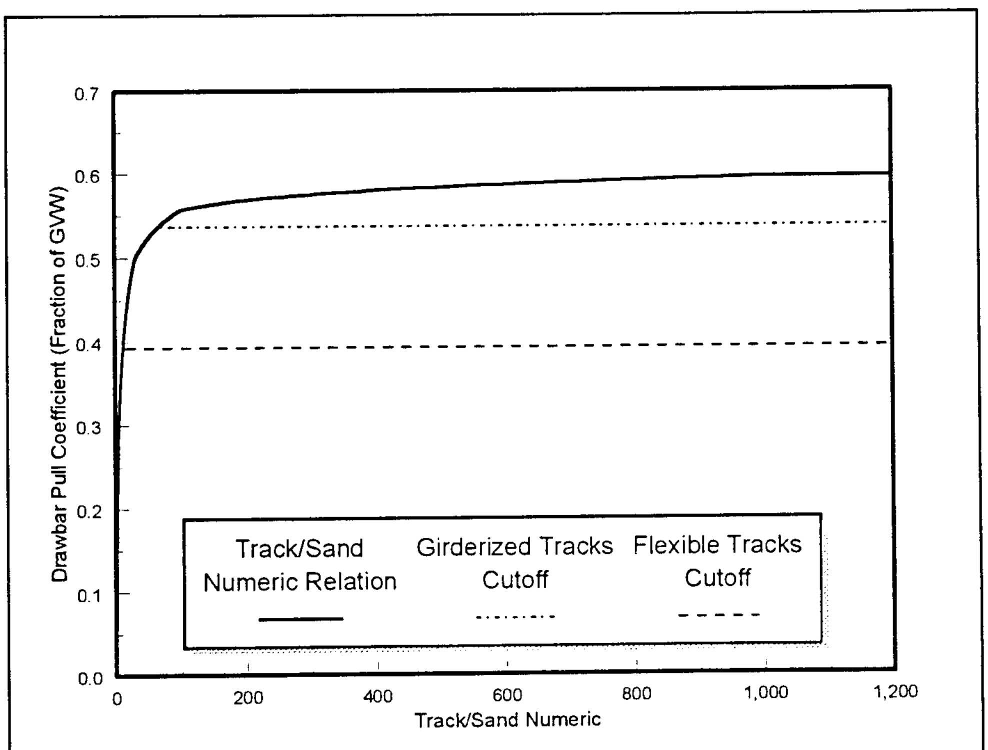


Figure 9. Track/sand numeric use in drawbar at nominal slip predictions for tracked vehicle traction on coarse-grained soils

Wheeled Vehicles on Coarse-Grained Soils

NRMM II models wheeled vehicle traction on coarse-grained soils using the Numeric Methodology. The λ term is the powered-wheel/sand numeric (Π_P) for D/W predictions and the unpowered-wheel/sand numeric (Π_U) for R/W predictions. Π_P and Π_U are dimensionless parameters composed of traction influencing vehicle characteristics and terrain characteristics. The terrain influence is accounted for through the Cone Index (CI) measure of soil strength. Nominal slip and maximum-pull slip are both 15%. The following three traction modeling parameters are used to obtain the "soil corrected" tractive force - speed relation:

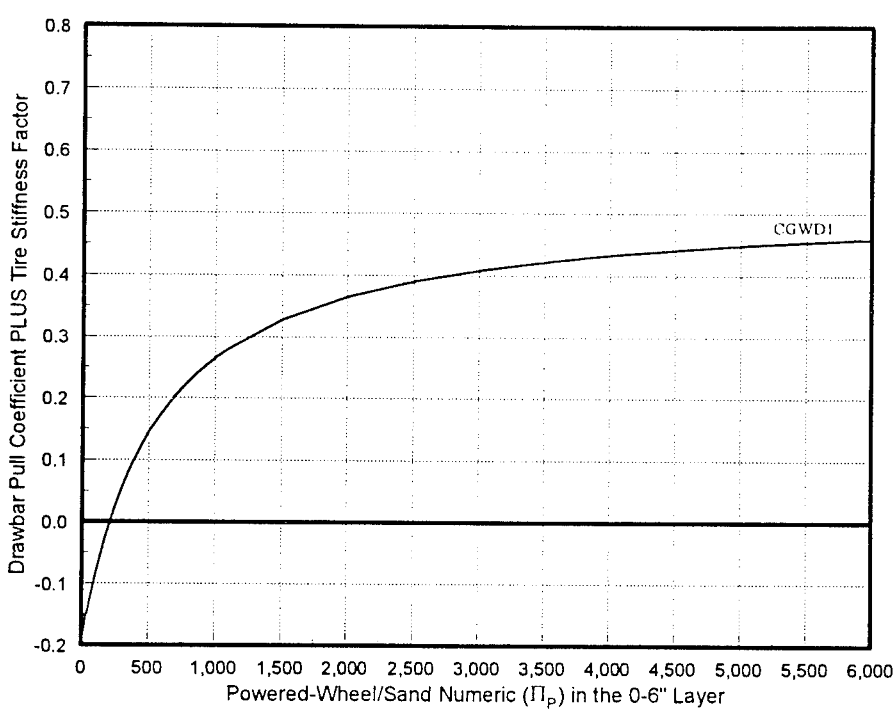
(1) Wheeled Drawbar at Nominal Slip on Coarse-Grained Soils,

(2) Wheeled SLIP at "Maximum" SS on Coarse-Grained Soils, and

(3) Wheeled Motion Resistance on Coarse-Grained Soils.

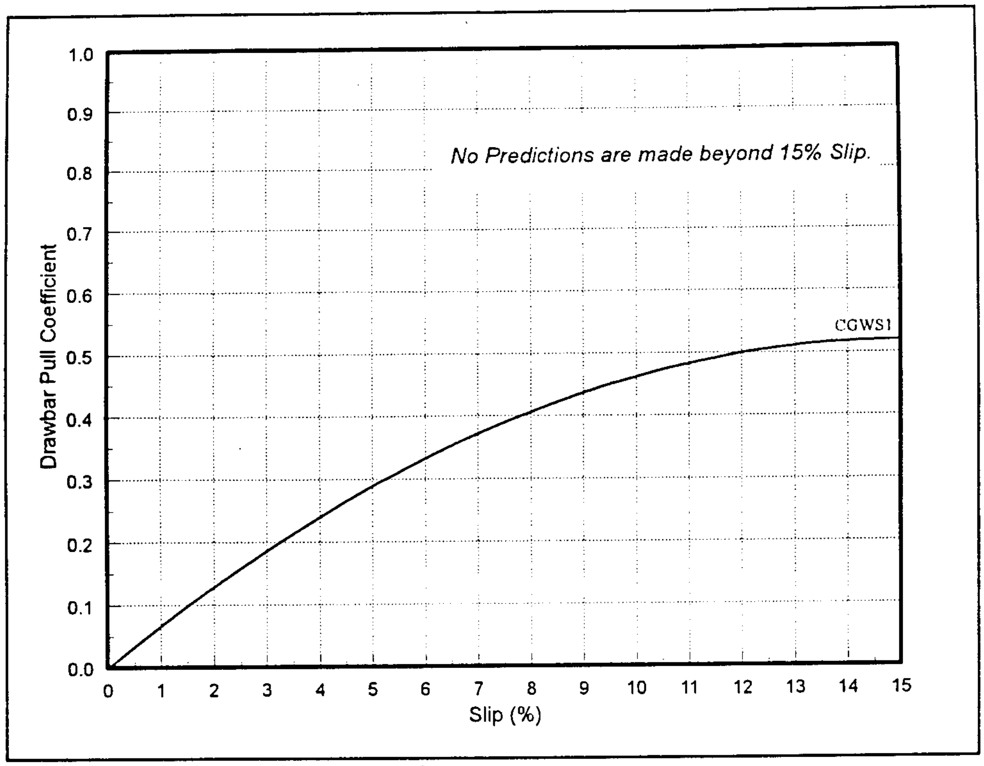
The relationships for these parameters are presented in Table 9. Figure 10 presents a graphical view of the families of prediction curves.

Π_P was developed from controlled laboratory testing with single tires in an attempt to obtain a single numeric from which all necessary wheeled modeling performance parameters could be evaluated. Π_U is simply a variant of Π_P for use in R/W predictions. Another minor parameter used in making the D/W and R/W predictions is the tire stiffness factor (X_{TS}). It represents a relative internal tire motion resistance coefficient, and

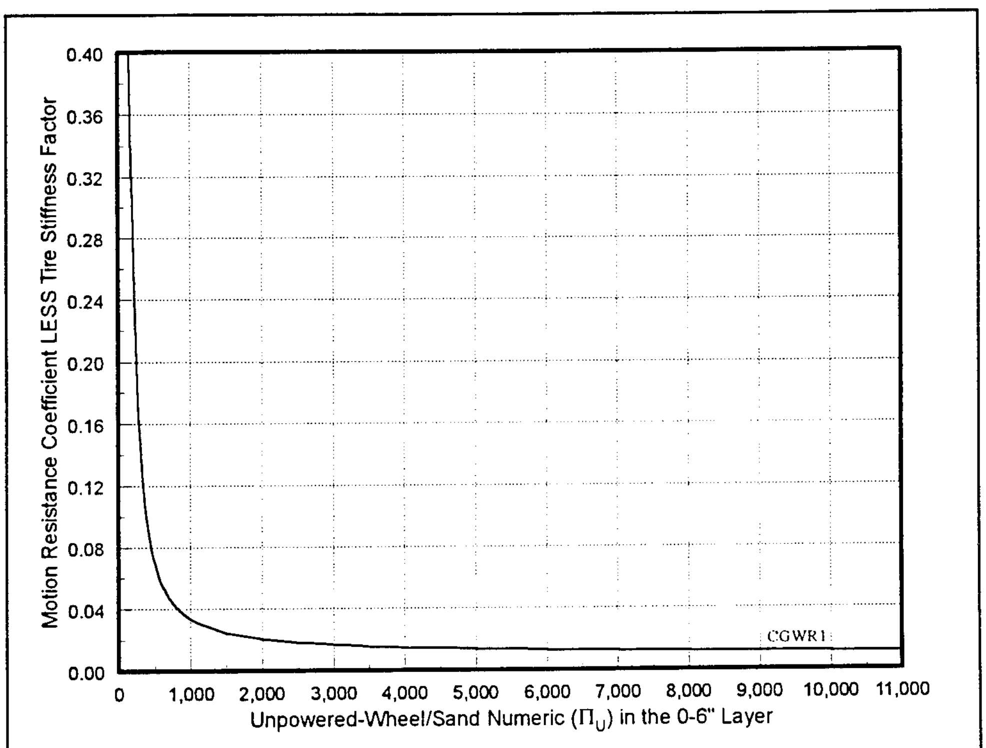


a. Drawbar at Nominal Slip

Figure 10. Families of prediction curves for wheeled vehicle traction on coarse-grained soils (Continued)



b. Slip at "Maximum" Soil Strength



c. Motion Resistance

Figure 10. (Concluded)

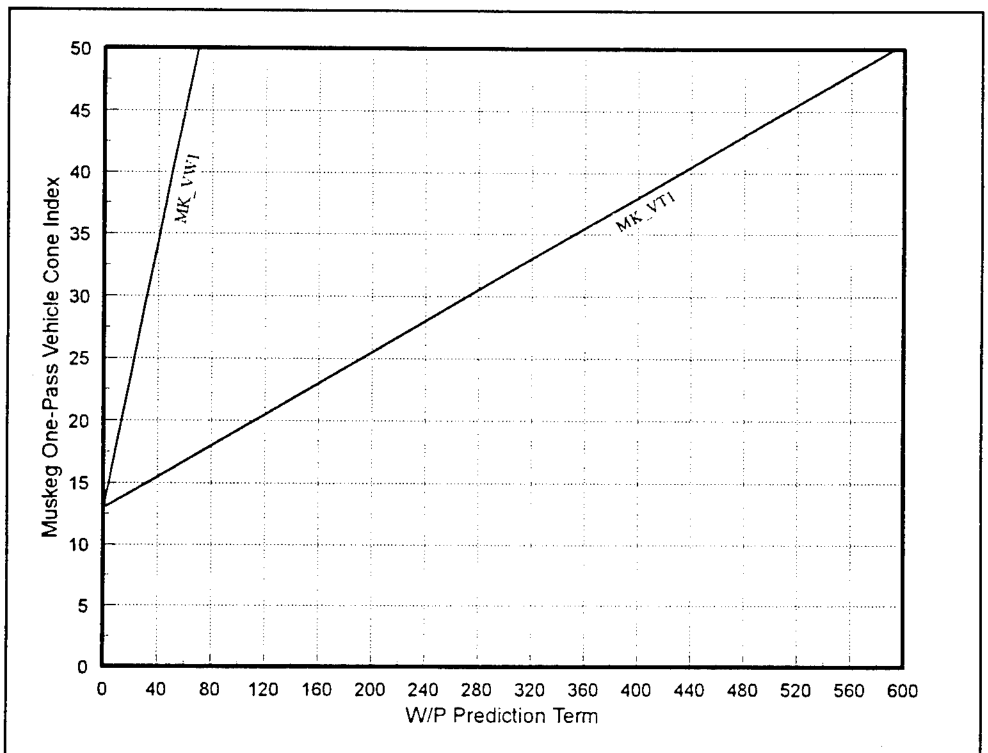
therefore is subtracted from the D/W equation and added to the R/W equation. X_{TS} is typically less than 0.023 (δ/h = 0.45) for radial tires and 0.046 (δ/h = 0.35) for bias ply tires.

Vehicles on Muskeg

NRMM II models vehicle traction on muskeg terrain using the VCI_1 Methodology. The vehicle influence is accounted for with the weight over perimeter factor (W/P). The terrain influence is accounted for with the Cone Index (CI) measure of soil strength. The λ term is CI_X for both D/W and R/W predictions, where CI_X equals CI minus $VCI_{1(MK)}$. Nominal slip is 20% and maximum-pull slip is 100%. The following four traction modeling parameters are used to obtain the "soil corrected" tractive force - speed relation:

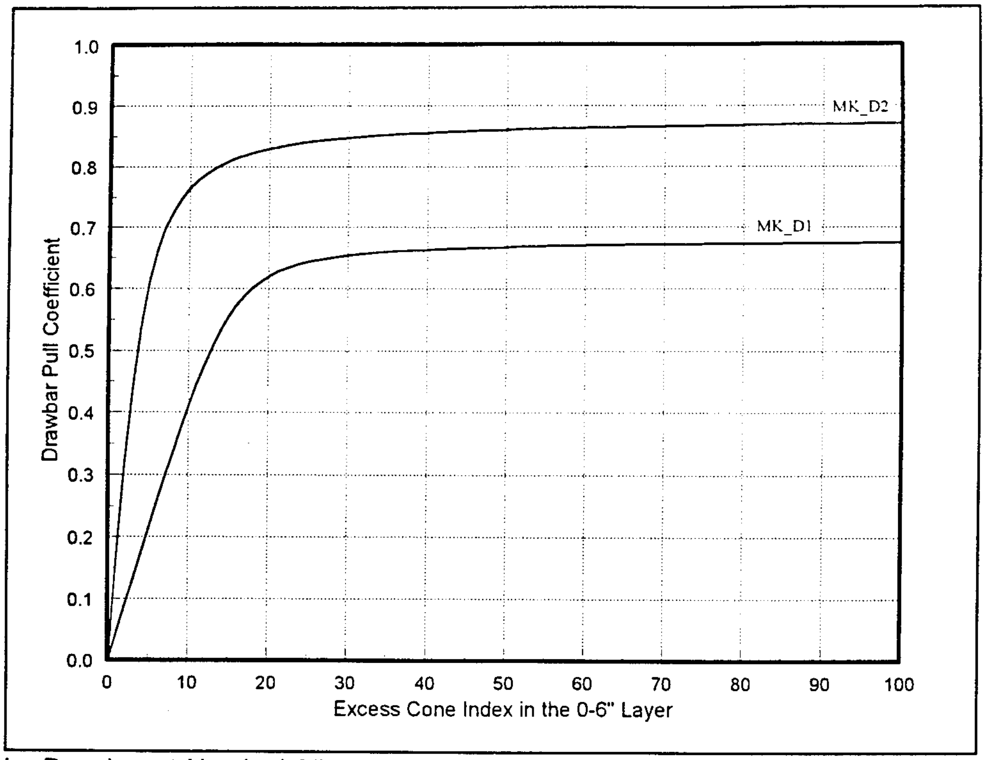
(1) Muskeg One-Pass Vehicle Cone Index,
(2) Muskeg Drawbar at Nominal Slip,
(3) Muskeg Slip at "Maximum" SS, and
(4) Muskeg Motion Resistance.

Table 10 contains the empirical relationships used for each of these muskeg traction modeling parameters. Figure 11 presents a graphical view of the families of prediction curves.

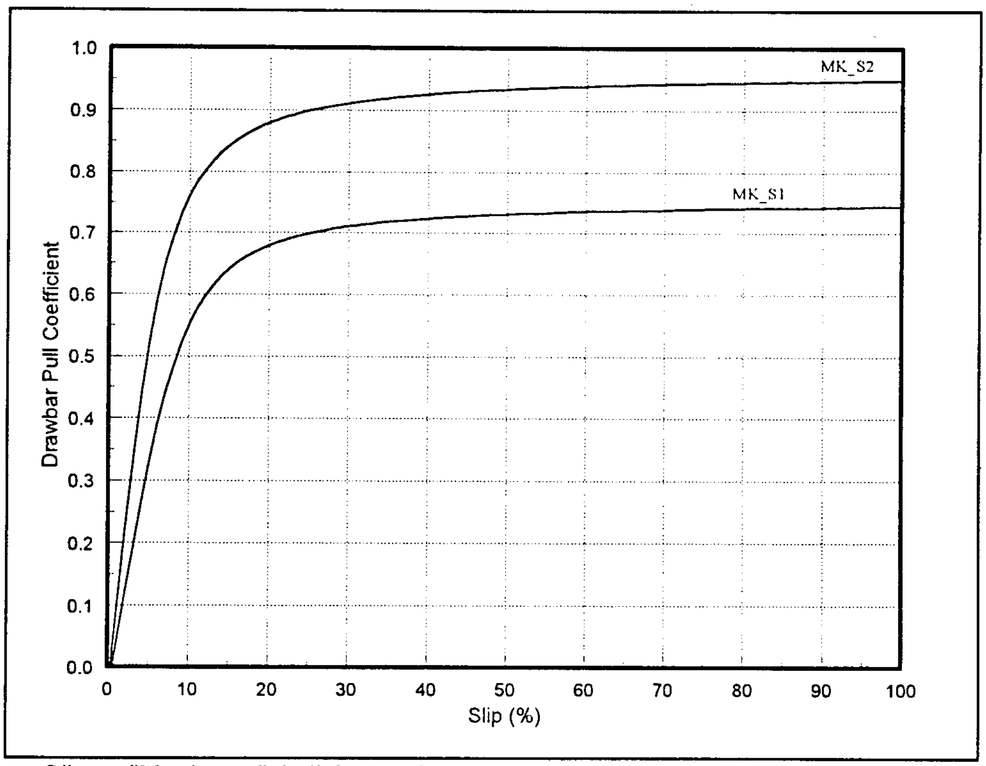


a. One-Pass Vehicle Cone Index

Figure 11. Families of prediction curves for vehicle traction on muskeg soils (Continued)

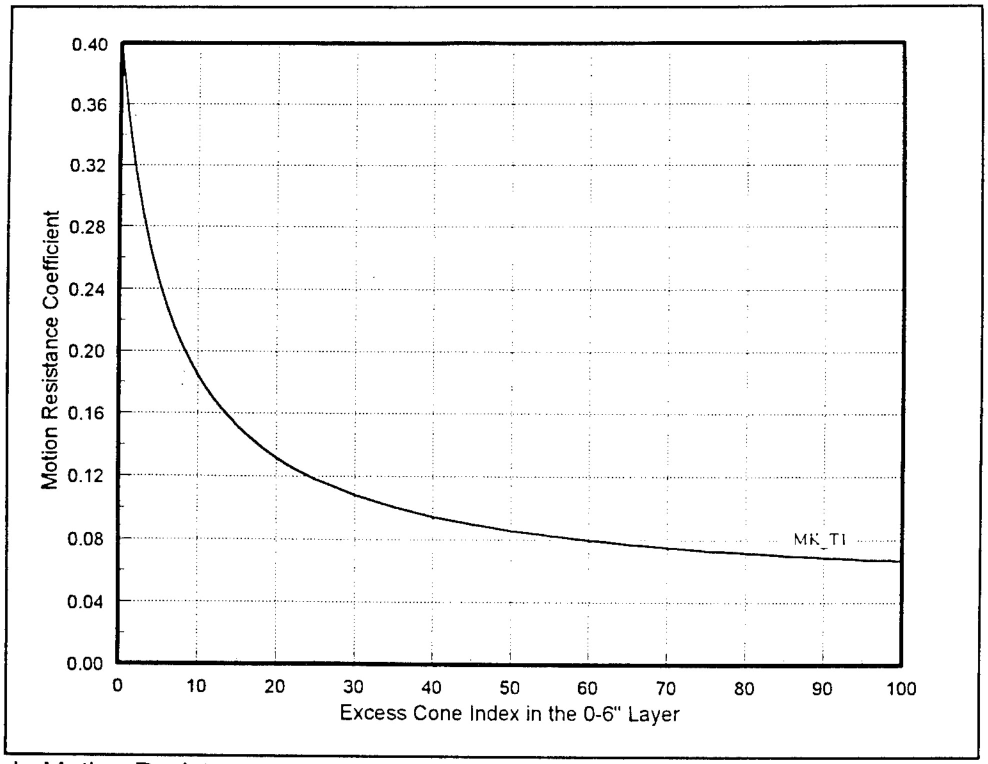


b. Drawbar at Nominal Slip



c. Slip at "Maximum" Soil Strength

Figure 11. (Continued)



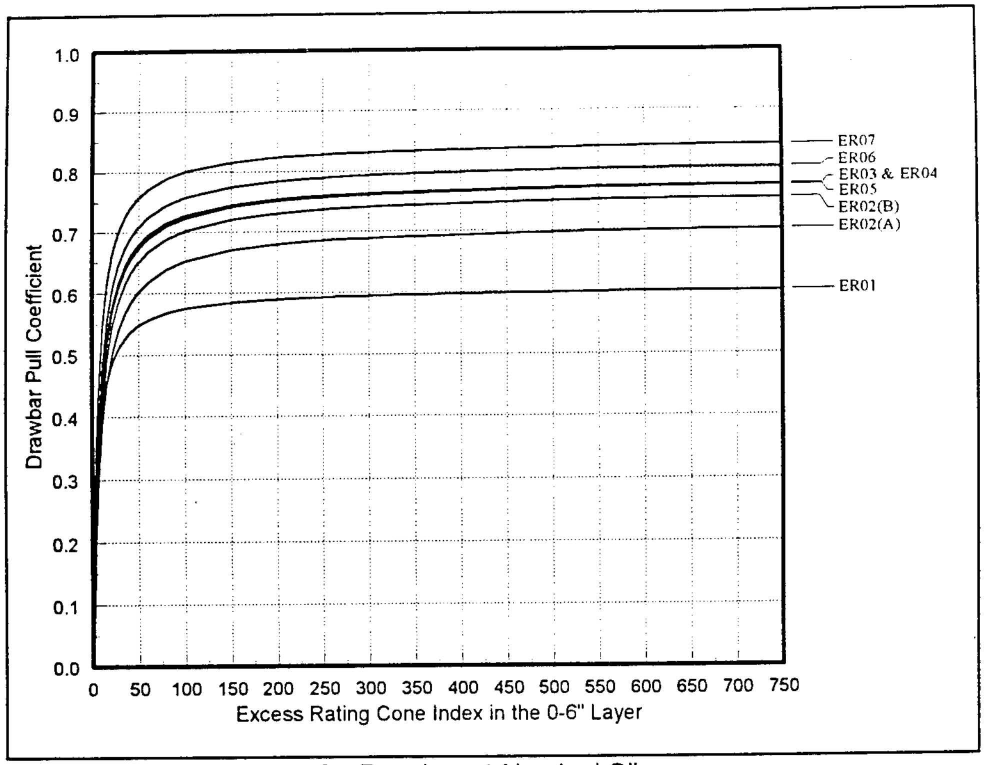
d. Motion Resistance

Figure 11. (Concluded)

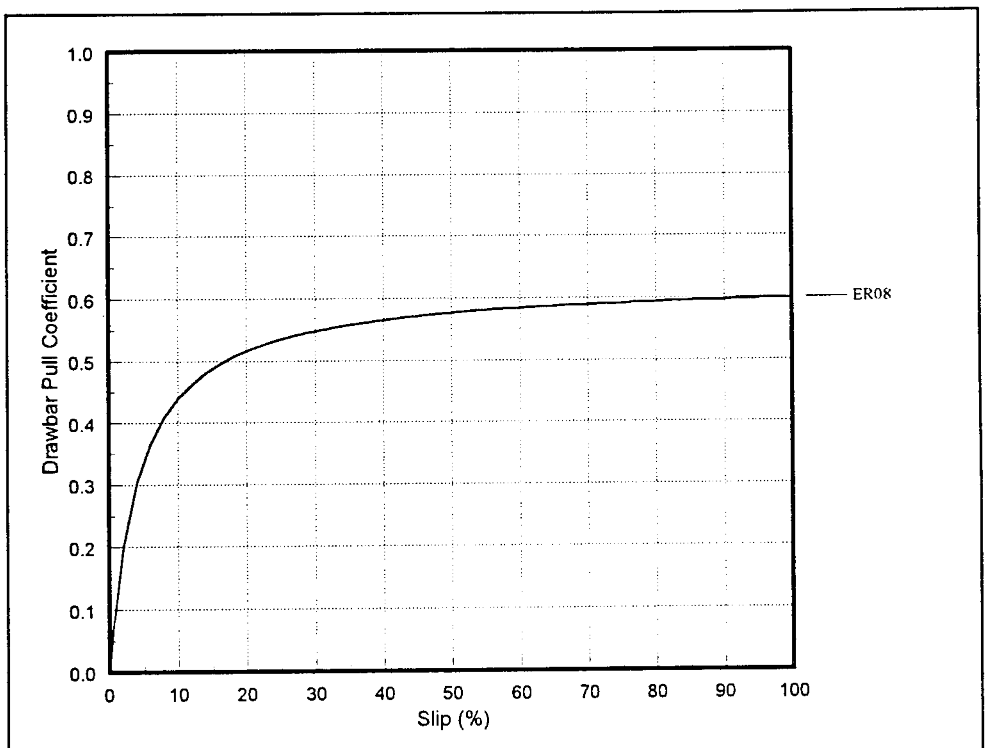
Proposed Changes in Relationship Equations

During the course of this research, qualitative assessments of the empirical relationships were made with scatter plots comparing the gathered data to the relationship prediction equations. This was also done to make certain no nonsense data were used. The agreement between the gathered data and the prediction curves was acceptable for most of the relationships, but for some it was not. Improved prediction equations were established for a few, but not all, of the relationships with poor agreement. Improved prediction equations were established only if a database contained at least all of the data used in the original development of the relationship. This constraint insured that no hasty changes were made without a thorough investigation. The constraint limited improvements to only the relationships for vehicle traction on fine-grained soils.

Improved prediction equations were established for all eight of the Fine-Grained Drawbar at Nominal Slip relationships and for one of the Fine-Grained Slip at "Maximum" Soil Strength relationships. These new prediction equations are presented in Table 11, and they are graphically presented in Figure 12. Scatter plots designed for comparison of the measured data to the current and the proposed new prediction equations are presented in this report, but reference to these plots is deferred until the databases have been introduced in Chapter 3.



a. Proposed new curves for Drawbar at Nominal Slip



b. Proposed new curves for Slip at "Maximum" Soil Strength

Figure 12. 1994 proposed new prediction curves for vehicle traction on fine-grained soils

3 The Databases

Databases have been created for use in characterizing the internal variability of the NRMM II empirical relationships for predicting vehicle traction on cross-country terrain. Databases created for the following Vehicle/Terrain Interaction (VTI) categories are addressed in the scope of this report:

(1) Vehicles on Fine-Grained Soils,
(2) Tracked Vehicles on Coarse-Grained Soils,
(3) Wheeled Vehicles on Coarse-Grained Soils, and
(4) Vehicles on Muskeg.

The following sections describe the general contents, the developmental steps, and the applicability of the databases developed for each of these VTI categories.

To prevent confusion, it should be noted that this document uses the term database to represent an abstract entity, and one database can be comprised of smaller databases. Terms like sub-databases will not be used. For example, this document discusses the development of a single database for NRMM II Cross-Country Traction. Within this database is a single database for Vehicles on Fine-Grained Soils, a single database for Tracked Vehicles on Coarse-Grained Soils, etc. Within the database for Vehicles on Fine-Grained Soils is a single database for Fine-Grained One-Pass Vehicle Cone Index and so on.

Vehicles on Fine-Grained Soils

Fine-Grained One-Pass Vehicle Cone Index

The *Fine-Grained One-Pass Vehicle Cone Index* database contains vehicle configuration characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration characteristics include tire size, tire pressure, track size, a tire chains flag (yes or no), and test gross vehicle weight (GVW). The measured performance information provides the critical soil layer and the corresponding measured Fine-Grained VCI_1. It does not provide the "root" multi-pass test data from which the measured VCI_1 is interpreted (see Appendix A for information on test procedures). This type of information is available in the RCI3.PRN digital database maintained at MSD for most of the data contained in the *Fine-Grained One-Pass Vehicle Cone Index* database. The data background information contains the primary referenced data source and the name of the NRMM II vehicle-file used for the VCI_1 prediction. The predicted performance information is the NRMM II predicted Fine-Grained VCI_1.

The measured VCI_1 values were taken as reported in the primary referenced data sources unless a re-evaluation of the "root" multi-pass test data was necessary. Re-evaluations of the "root" data were conducted for several of the available sources, and if necessary, the measured VCI_1 values were re-interpreted based on the latest accepted critical layer rules. Using the latest critical layer rules changed the measured VCI_1 values obtained from primarily the older sources (when critical layer rules other than the currently accepted rules were used and when 50-pass VCI testing was the norm) and those obtained for a few extremely heavy (average wheel load > 10,000 lbf [2]) wheeled vehicles.

In the development of the *Fine-Grained One-Pass Vehicle Cone Index* database, all of the available multi-pass test data generated during the history of WES mobility testing were investigated. The test dates for these multi-pass tests spanned a period from the late nineteen fifties through 1992. The data involved tracked vehicles and wheeled vehicles with both powered and unpowered axles. They also involved U.S. military, foreign military, and civilian vehicles. The data primarily involved testing on CH soils, but some involved testing on CL, ML, and SM soils.

Almost all of the investigated multi-pass data were used to develop the database provided that the data involved testing on CH soils. Only the data from testing on CH soils were used because the VCI_1 relationships are conservatively based on CH soil performance. Any data involving unusual concept vehicles, like the Major/Minor (Robinson and Rush 1968), were not used to develop the database. Any data for which a VCI_1 value could not be adequately determined, like the Two-Wheel-Drive Industrial Tractor data (Rush and Stinson 1967), were not used to develop the database.

Table 12 lists all of the vehicle configurations contained in the database with their respective data sources. Plates 1 and 2 show scatter plots of the measured data with the NRMM II prediction curves for the relationships. The plates indicate that both databases are adequate for a conjectural evaluation of the variability in the relationships.

For the purpose of creating Plates 1 and 2, the MI values for the vehicles have been back-calculated from the Vehicle $VCI_{1(FG)}$ values output from the Combination VCI Routine. For Plate 1, it was also necessary to adjust the measured Vehicle $VCI_{1(FG)}$ values by dividing them by the deflection correction factors. The deflection correction factors were computed using the average deflection ratios (δ/h) for the vehicles. The plates were presented with MI on the vertical axis (though MI is the independent

[2] A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page vii.

variable) to conform with historical methods of presenting VCI prediction curves.

Fine-Grained Drawbar at Nominal Slip

The *Fine-Grained Drawbar at Nominal Slip* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration characteristics include GVW, tire size, tire pressure, hard surface deflection, a tire chains flag (yes or no), track type, a relative CPF flag (relative to 4 psi), and the NRMM II predicted VCI_1. The measured soil characteristics are the USCS soil type and the 0-6 RCI. The measured performance information includes the slip and the drawbar coefficient. The primary reference source and a data comment entry make up the data background information. The predicted performance information consists of the 0-6 inch RCI_X and the NRMM II predicted $D/W_{Nom.}$.

Nominal slip is currently 100% for the Fine-Grained Drawbar at Nominal Slip empirical relationships, but nominal slip was 20% until NRMM II was officially adopted in 1993. Most of the published reports, even current reports, usually provide the 20% slip D/W value (D/W_{20}) because on fine-grained soils, it is very close to the optimum D/W value ($D/W_{Opt.}$), and many of these reports do not include the "root" drawbar pull - slip test data from which the 100% slip D/W value (D/W_{100}) could be determined. Other reports provide the $D/W_{Opt.}$ values for which the slip is typically in the range from 15% to 30%, and some, specifically those published in the nineteen sixties, provide the maximum-pull D/W values (D/W_{MP}) for which the slip is unknown and typically ranges from 20% to 100%. Since the quantity of data available for evaluating these relationships is so limited, all of the available data were included in the *Fine-Grained Drawbar at Nominal Slip* database regardless of whether the reported D/W was D/W_{20}, $D/W_{Opt.}$, D/W_{100}, or D/W_{MP}. When the "root" drawbar pull - slip data were available, they were usually evaluated for D/W_{20} or D/W_{100} if these drawbar coefficients were not directly reported.

Including all of the data resulted in two databases for Fine-Grained Drawbar at Nominal Slip: (1) a 20% Slip database, and (2) a 100% Slip database. The 20% Slip database contains D/W_{20} data and $D/W_{Opt.}$ data since on fine-grained soils D/W_{20} is typically representative of $D/W_{Opt.}$. The 100% Slip database contains D/W_{100} data and D/W_{MP} data since on fine-grained soils D/W_{100} is typically representative of D/W_{MP}. The two databases joined together provide a sound tool for evaluating or modifying the Fine-Grained Drawbar at Nominal Slip empirical relationships.

It may seem illogical to evaluate relationships that are empirically based on D/W_{100} data with D/W_{20} data, but this is not the case. The D/W_{20} data can be used to evaluate the D/W_{100} relationship by shifting the D/W_{100} relationship to D/W_{20} magnitude. This can be done using the NRMM modeling hypothesis that the shape of the slip curve for a particular VTI relationship is the same for all soil strengths, and only the relative

D/W magnitude of the slip curve changes as a function of soil strength. This means that a Drawbar at Nominal Slip relationship can be shifted based on the shape of its respective Slip at "Maximum" Soil Strength relationship. This hypothesis is used in NRMM to obtain the first point on the "soil corrected" tractive force - speed relation using the formula below

$$T_{Soil} = \left[\frac{D_P}{W_{P_{Nom}}}^{SS} + \left(\frac{D}{W}_{MP}^{Max} - \frac{D}{W}_{Nom}^{Max} + \frac{R_P}{W_P}^{SS} \right] GVW_P COS$$

as was discussed in the Implementation Overview section of the Implemented Use of the Relationships part of Chapter 2. The three drawbar pull coefficients represent the implementation of the modeling hypothesis in that they are used to shift the D/W at nominal slip and SS relationship to a D/W at maximum-pull slip and SS relationship as shown below.

$$\frac{D_P}{W_{P_{MP}}}^{SS} = \frac{D_P}{W_{P_{Nom.}}}^{SS} + \left(\frac{D}{W}_{MP}^{"Max"} - \frac{D}{W}_{Nom.}^{"Max"} \right)$$

Maximum-pull slip and nominal slip can be arbitrarily set to any slip magnitudes. Therefore the D/W_{20} data can be used to evaluate the Fine-Grained Drawbar at Nominal Slip relationships (though nominal is 100%) using the formula below to obtain the shifted version of the relationships.

$$\frac{D_P}{W_{P_{20}}}^{RCI} = \frac{D_P}{W_{P_{100}}}^{RCI} + \left(\frac{D}{W}_{20}^{"Max"} - \frac{D}{W}_{100}^{"Max"} \right)$$

The first stage in the development of the *Fine-Grained Drawbar at Nominal Slip* database was to gather all of the data that could possibly be used. First was the development of a digital database (CR3-152.WB1) with drawbar pull - slip data from the "One-Pass" report (Nuttall, Wilson, and Werner 1966). All of the "One-Pass" testing was done on soils with RCI < 200. Next, plots of D/W versus slip for the "One-Pass" data, worked up originally during the development of AMC-71, were located. The new "One-Pass" database was used in conjunction with these original plots to establish the D/W_{20} values. The D/W_{100} values were usually not obtainable for the "One-Pass" data because that research program typically did not report data for which the slip exceeded 80%.

Next, the database was updated to include data from all of the available sources for drawbar pull testing on fine-grained soils with RCI < 200. The database was then upgraded again to include the data from the Wheeled versus Tracked Program (Willoughby et al. 1991). All of the Wheeled versus Tracked data were from testing on soils with RCI > 200. There were several more available sources with drawbar pull test data from testing on fine-grained soils with RCI > 200, but these sources typically contained only small amounts of data. Therefore, all of these sources were not used to develop the database, but some were used in order to fully encompass the range of vehicles tested by WES. This concluded the first stage.

The second stage was to scrutinize the data and transfer any data considered bad or not applicable to a "reject" database. The philosophy used was to keep any data for which no substantial reason could be found for "rejecting" it (transferring it to the "reject" database). Data involving vehicles that were not representative of the relationships they were intended to represent were "rejected", data from bad sources were "rejected", and a couple of obvious outlier points were "rejected".

The final stage was to segregate the database according to particular variables not isolated by the NRMM II relationships. The purpose was to identify any separate trends that would have less variability and for which new NRMM relationships could be proposed. The first segregation separated vehicles into three categories: (1) U.S. military vehicles with standard configurations, (2) U.S. military vehicles with modified configurations, and (3) all other vehicles including foreign military and civilian vehicles. The results produced no significant separation of trends and showed no significant difference in variability between the three categories. Figure 13 shows a scatter plot illustrating the typical results of this first segregation. A second segregation separated the vehicle configurations into four categories based on relative tire pressure/deflection scenarios: (1) highway, (2) cross-country, (3) mud/sand/snow, and (4) emergency. The results of this segregation also produced no significant separation of trends and showed no significant difference in variability between the four categories. Figure 14 shows a scatter plot illustrating the typical results of this second segregation. After a small amount of time was spent investigating the possible benefits of segregating the data beyond the limits of the NRMM II relationships, it was decided that the variability evaluations should be conducted on the relationships in their current form.

Tables 13 and 14 lists all of the vehicle configurations and respective sources that were used in the *Fine-Grained Drawbar at Nominal Slip* database. Tables 15 and 16 lists all of the vehicle configurations and respective data sources that were "rejected" from the database. Plates 3 through 10 show scatter plots of the measured data in the 100% Slip database with the current NRMM II prediction curves as well as the proposed new prediction curves introduced in Chapter 2. Plates 11 through 18 show scatter plots of the measured data in the 20% Slip database with the shifted prediction curves, current and proposed new. The plates indicate that these databases are adequate for a conjectural evaluation of the variability in the relationships. The plates also demonstrate that the current prediction curves are predicting too low and that the proposed new prediction curves conform better to the data trends.

Although both the 100% Slip and the 20% Slip databases can be used to evaluate the relationships, evaluations should focus primarily on the 20% Slip database. The samples are typically better (more data points and better distribution throughout the applicable RCI_X range) for the 20% Slip database. Another reason is because there is always less quality control in drawbar pull - slip testing at the 100% slip condition than at the 20% slip condition.

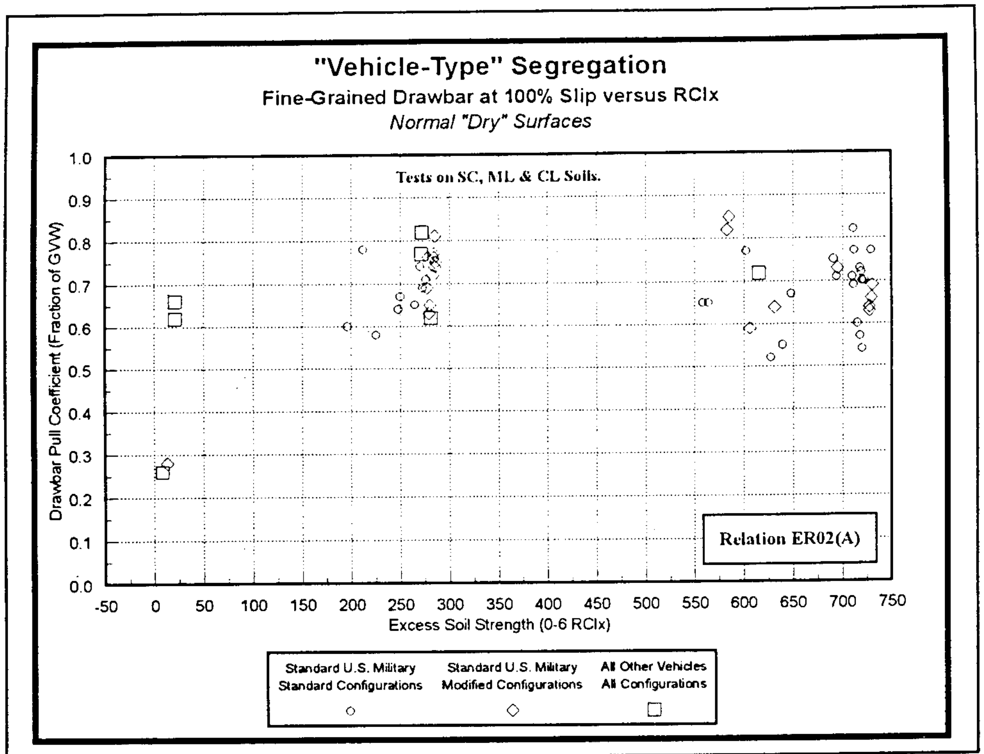


Figure 13. Typical results of the first data segregation for the Fine-Grained Drawbar at Nominal Slip relationships

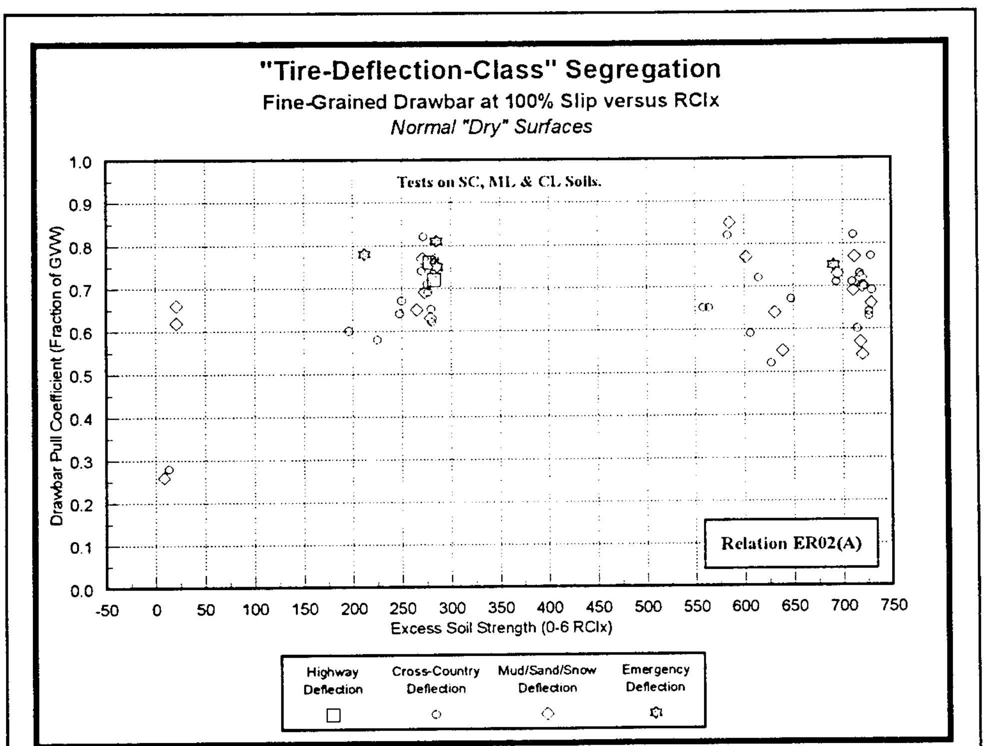


Figure 14. Typical results of the second data segregation for the Fine-Grained Drawbar at Nominal Slip relationships

Fine-Grained Slip at "Maximum" Soil Strength

The *Fine-Grained Slip at "Maximum" Soil Strength* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, and data background information. The vehicle configuration characteristics include tire size, tire pressure, a tire chains flag (yes or no), track size, a track pads flag (yes or no), GVW, and a relative CPF flag (relative to 4 psi). The measured soil characteristics include the test location, test site, USCS soil type, and soil surface condition (simulated rainfall amount). The measured performance information consists of the motion resistance, drawbar pull, D/W, and slip. The data background information provides the test date, and the primary reference source.

Two oddities of the database are that it contains motion resistance data, which is not needed for evaluating the Fine-Grained Slip at "Maximum" Soil Strength relationships, and that it does not contain RCI, which is a factor. The reason it contains motion resistance is because the data were obtained directly from drawbar pull - slip tests and, at WES, towed motion resistance tests are usually conducted concurrent with drawbar pull - slip tests. The motion resistance data were entered into these database files with the original intent of later transferring them to a motion resistance database, but they were left in these files as an extra. RCI is not in the database because the exact RCI value associated with each test is not necessary information for evaluation of these relationships. The only requirement is that the RCI values of the data in the database must be within the range of the RCI values of the data used to develop the empirical relationships. This was definitely the case here since the database contains the same data used in the development of these relationships.

Three sources were investigated for this database: (1) the Wheeled versus Tracked Program, (2) The MEXA Program (Schreiner 1971), and (3) the Major/Minor data (Robinson and Rush 1968). The Wheeled versus Tracked Program generated an enormous quantity of drawbar pull - slip test data, and it was the only source of data used to establish the many new slip relationships when NRMM was upgraded from edition I to edition II. The only data taken from the MEXA Program were from testing on soils with RCI > 40 with wheeled and tracked vehicles having CPF < 4 psi. The MEXA Program also generated data for other types of vehicles, but these data were not used because they involved soils with RCI < 200 whereas the relationships for which they would apply were based on soils with RCI > 200. The Fine-Grained Slip at "Maximum" Soil Strength relationships for wheeled vehicles having CPF < 4 psi are the only ones for which the Wheeled vs. Tracked Program produced no data. Since the MEXA Program originally led to the development of these slip relationships, it was investigated here. The Major/Minor source also involved drawbar pull - slip testing of a wheeled vehicle having CPF < 4 psi, and therefore, it was investigated also in order to fill the Wheeled versus Tracked void.

After the initial data gathering, the data were scrutinized. The Major/Minor data set was not kept in the database because it involves an unusual, power-limited, concept vehicle. That data set was transferred to a "reject" database file. The Wheeled versus Tracked data set for the SUSV, a tracked vehicle having CPF < 4 psi, operating on non-slippery surface conditions was "rejected" also. This data set was "rejected" because the SUSV was designed specifically for operations on snow and ice covered terrain, and it demonstrates unique slip performance on non-slippery fine-grained soils. Contrarily, the Wheeled versus Tracked data set for the SUSV operating on slippery soils contains the only data available for tracked vehicles having CPF < 4 psi operating on slippery soils, and therefore, it was retained.

As stated, the *Fine-Grained Drawbar at Nominal Slip* database was upgraded with some of the other available sources for drawbar pull - slip testing on fine-grained soils with RCI > 200. That upgrade was done for the sake of investigating the full range of vehicles tested at WES. This step was avoided here for time economy after it was realized that the data from the additional sources, when added to the *Fine-Grained Drawbar at Nominal Slip* database, all randomly fit within the scatter of the Wheeled versus Tracked data. The additional sources would not have significantly benefited the *Fine-Grained Slip at "Maximum" Soil Strength* database in terms of variability evaluation. Therefore, the Wheeled versus Tracked Program and the MEXA Program were the only two sources used.

Tables 17 and 18 lists all of the vehicle configurations and respective sources that are contained in the *Fine-Grained Slip at "Maximum" Soil Strength* database. Plates 19 through 42 show scatter plots of the measured data with the NRMM II prediction curves. Plate 19 also shows the proposed new prediction curve for relationship ER08, and it demonstrates that the proposed new prediction curve conforms better to the data trend than the current one. The plates indicate that all of these databases are adequate for evaluation of the variability in the relationships except the database for ER22 (Plate 33). The database for ER22 does not reflect the realistic variability in this relationship because the database only contains data from testing of one vehicle at one site. The variability in ER22 would be more similar to that in ER20 (Plate 31) and ER21 (Plate 32) than the database for ER22 indicates.

Fine-Grained Motion Resistance

The *Fine-Grained Motion Resistance* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration characteristics include the tire size, a tire construction flag (bias or radial), tire deflection, GVW, a relative CPF flag (relative to 4 psi), and the NRMM II predicted VCI_1. The measured soil characteristics provide test location, USCS soil type, soil surface condition (simulated rainfall amount), and RCI for at least the 0-6 inch layer. The measured performance information is the motion resistance coefficient. The data background information is comprised of the primary reference source, and data remarks. The 0-6 inch RCI_X and

NRMM II predicted motion resistance coefficient provide the predicted performance information.

The database is a modified version of a database developed during previous stochastic vehicle mobility forecasting efforts. The original database was obtained, the data were segregated into areas for each of the NRMM II empirical relationships for fine-grained motion resistance, and then the database contents were slightly modified. The original database contained data from the two big sources for towed motion resistance test data: (1) the MEXA Program (Schreiner 1971) and (2) the Wheeled vs. Tracked Program (Willoughby et al. 1991). It also contained data from some other available sources involving testing on RCI < 200 soils and data from some of the more recent sources involving testing on RCI > 200 soils. It was decided that the database was sound and that no other sources should be investigated for addition to the database due to time constraints. It was then observed that the database did not contain all of the tracked vehicle data from the Wheeled vs. Tracked Program, so those data were added.

After adding the missing Wheeled vs. Tracked data, the database was scrutinized. Some data were transferred to a "reject" database because they involved testing in wet plowed fields or in coarse-grained soil, and other data were "rejected" because they involved unusual concept vehicles like the XM759 Airoll Vehicle (Schreiner and Rula 1968). Some of the data were "rejected" because they were obtained from the "One Pass" report (Nuttall, Wilson, and Werner 1966). The "One Pass" motion resistance data were not towed motion resistance data but were instead estimated from other measured parameters. The only other data "rejected" were the SUSV data from the Wheeled vs. Tracked Program. This data set was "rejected" because the SUSV was designed specifically for operations on snow and ice covered terrain, and it has high motion resistance relative to other tracked vehicles that has yet to be thoroughly investigated.

The database contains most of the towed motion resistance data available at MSD from testing on soils with RCI < 200. Contrarily, there are several available sources for motion resistance data from testing on soils with RCI > 200 with slippery and non-slippery surface conditions that were not investigated. The database does, however, contain most, if not all, of the motion resistance data that were used to establish the current relationships in NRMM II. The database also covers the range of vehicles tested at WES well.

There are some NRMM II Fine-Grained Motion Resistance relationships that are not provided for by the database. The database provides data for all of the tracked relationships. It also provides data for all of the powered wheeled relationships except for MR18. There has never been any testing by WES that would support MR18. It appears that this relationship was extrapolated based on the change in the other relationships when going from the non-slippery to the slippery surface condition. The database also does not provide data for the unpowered wheeled relationships MR08 and MR09. Although the database does not facilitate direct evaluation of these three relationships, it does provide data for 17 of the 20 Fine-Grained Motion Resistance relationships in NRMM II and should provide insight into the variability of all these relationships.

Databases were not developed for the unpowered wheeled relationships MR08 and MR09 because the applicability of these relationships is questionable. These relationships were empirically based on a small set of data that was also used to develop some of the powered wheeled relationships, but they were derived using the Numeric Methodology rather than the VCI_1 Methodology. All of the relationships are empirically based on towed motion resistance data (i.e. unpowered), and therefore, the logic behind applying the VCI_1 Methodology to powered wheeled assemblies and the Numeric Methodology to unpowered wheeled assemblies is not apparent. It would seem more logical for all of the relationships to be termed "unpowered" relationships and for the assumption to be made, as in the case of tracked assemblies, that the motion resistance for powered and unpowered wheeled assemblies is essentially the same since measuring the motion resistance for a powered assembly is extremely difficult, if not impossible.

Tables 19 and 20 lists all of the vehicle configurations and respective sources that are contained in the *Fine-Grained Motion Resistance* database. Plates 43 through 59 show scatter plots of the measured data with the prediction curves for the relationships. The plates indicate that all of these databases are adequate for a conjectural evaluation of the variability in the empirical relationships except the databases for MR06, MR11, MR16,and MR17. The data samples for these four exceptions are very small and do not convey a realistic variability in the relationships.

Tracked Vehicles on Coarse-Grained Soils

Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils

The *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database contains vehicle configuration information, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration information includes track width, track contact length, a track type flag (flexible or girderized), GVW, and number of assemblies. The measured soil characteristics consist of the test location, test site, and 0-6 inch CI. The measured performance information are drawbar pull, D/W, and slip. The year of testing, primary reference source, and data remarks provide the data background information. The predicted performance information is the track/sand numeric (Π_T) and the NRMM II predicted D/W.

Nominal slip is 20% for the Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils relationships, but some of the data in the database are D/W_{MP}. Maximum-pull data were entered only for vehicles that characteristically reach maximum drawbar pull at or near 20% slip such as the M29C Weasel whose typical drawbar performance with slip (Rush 1959) is shown in Figure 15. 40% slip D/W values were also included in

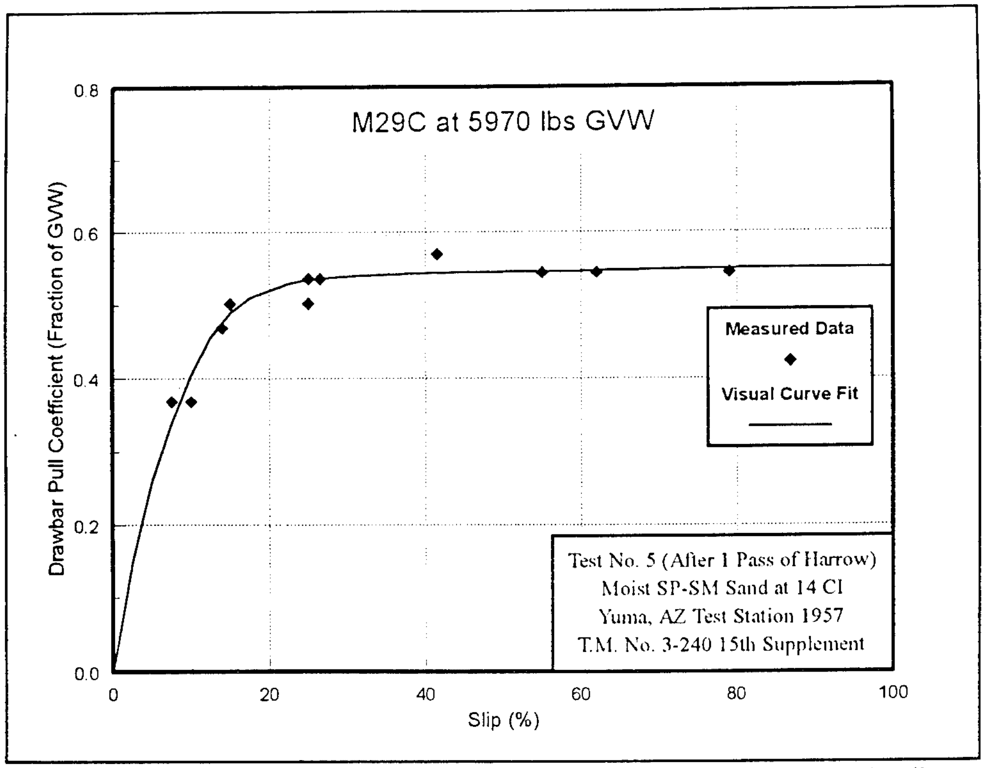


Figure 15. Typical drawbar versus slip for the M29C on coarse-grained soils

the database due to the findings of the 20th Supplement of T.M. No. 3-240 (Kennedy 1974). The 20th Supplement demonstrated that tracked vehicle drawbar at nominal slip and motion resistance on coarse-grained soils could be adequately modeled as constants with nominal slip being 40%, but this information was not implemented in NRMM II. Therefore, these data should not be used to evaluate the variability of the NRMM II empirical relationships.

Five sources were investigated for this database:

(1) Historical files on the AMC-71 Validation Program (Schreiner and Willoughby 1976),
(2) 15th Supplement of T.M. No.3-240 (Rush 1959),
(3) 17th Supplement of T.M. No.3-240 (Rush 1963),
(4) 20th Supplement of T.M. No.3-240 (Kennedy 1974), and
(5) Historical files on the MEACE Program (unpublished).

The 20th Supplement was a re-evaluation of the data presented in the 15th Supplement and the 17th Supplement, but it was used as a secondary reference source. The information necessary to use the data from the MEACE Program is incomplete because the vehicle configuration characteristics necessary for NRMM II predicted D/W could not be located. Therefore, these data can not be used, but the measured performance information was left in the database anyway. The investigated tests were primarily conducted on SP or SP-SM soils, but some of the data were from testing on arid SM soils of high CI.

No data were "rejected" from this database, but some sources are available that were not investigated. The Wheeled versus Tracked Program (Willoughby et al. 1991) involved drawbar pull - slip tests with flexible tracked vehicles on SP-SM soils with and without simulated rainfall. Also, a small validation of the track/sand numeric involving tests on mortar sand with rigid and flexible tracked vehicles was reported in Technical Report M-71-5 Report 3 (Turnage 1976). Because of the simplicity of the D/W performance of tracked vehicles on coarse-grained soils and because of time constraints, these sources were never investigated. It is possible that data from these other sources would improve the *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database in terms of being adequate for evaluating the variability in the relationships.

Table 21 lists the vehicle configurations and respective sources contained in the database. The MEACE information is not given in Table 21 since it is incomplete and can not be used to evaluate relationship CGTDG1. Plates 60 and 61 present scatter plots of the measured data with the NRMM II prediction curves. The plates indicate that both databases are adequate for a conjectural evaluation of the variability in the relationships. Plate 60 also indicates that some attention needs to be given to the modeling of drawbar for flexible tracked vehicles on coarse-grained soils. More testing is needed in this area.

Tracked Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils

The *Tracked Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database contains vehicle configuration information, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration information includes track width, track length, a track type flag (flexible or girderized), GVW, and number of assemblies. The measured soil characteristics are test location, test site, and 0-6 inch CI. The measured performance information provides the D, D/W, and slip. The date of testing, primary reference source, and data remarks provide the data background information. The predicted performance information is the NRMM II predictions for slip as a function of D/W and vice versa.

The sources investigated for the *Tracked Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database are the same as those investigated for the *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database. The data primarily involve testing conducted on SP or SP-SM soils, but some of the data were from testing on arid SM soils of high CI like desert pavement material. None of these data were "rejected", but data are available that were not investigated. The Wheeled versus Tracked Program generated some drawbar pull - slip test data for flexible tracked vehicles on SP-SM soils with and without simulated rainfall that could be used in this database, but they were not investigated primarily due to time constraints.

Table 22 lists the vehicle configurations and respective sources contained in the database. The MEACE information is given in Table 22 since it can be used to evaluate the relationship CGTSG1. Plates 62 and 63 present scatter plots of the measured data with the NRMM II prediction curves. The plates indicate that these databases are adequate for evaluation of the variability in the relationships.

Tracked Vehicle Motion Resistance on Coarse-Grained Soils

The *Tracked Vehicle Motion Resistance on Coarse-Grained Soils* database contains vehicle configuration information, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration information includes track width, track contact length, a track type flag (flexible or girderized), GVW, and number of assemblies. The measured soil characteristics are test location, test site, and 0-6 inch CI. The measured performance information provides the R and R/W values. The date of testing, primary reference source, and data remarks provide the data background information. The predicted performance information is the NRMM II predicted R/W.

The sources investigated for the *Tracked Vehicle Motion Resistance on Coarse-Grained Soils* database are the same as those investigated for the *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database except for the 15th Supplement of T.M. No.3-240 which did not contain any motion resistance data. The data primarily involve testing conducted on SP or SP-SM soils, but some of the data were from testing on arid SM soils of high CI. None of these data were "rejected", but data are available that were not investigated. The Wheeled versus Tracked Program generated some motion resistance data with flexible tracked vehicles on SP-SM soils with and without simulated rainfall, but they were not investigated primarily due to time constraints. It is probable that these additional data would improve the *Tracked Vehicle Motion Resistance on Coarse-Grained Soils* database in terms of being adequate for evaluating the variability in the relationships.

Table 23 lists the vehicle configurations and respective sources contained in the database. The MEACE information is given in Table 23 since it can be used to evaluate the relationship CGTRG1. Plates 64 and 65 present scatter plots of the measured data with the NRMM II prediction curves. The plates indicate that these databases are adequate for a conjectural evaluation of the variability in the relationships. The plates also indicate that when these relationships were developed, these data were not considered. The data used to define these relationships could be the Wheeled versus Tracked data, but this is improbable. It appears urgent that attention be given to the modeling of motion resistance for tracked vehicles on coarse-grained soils. More testing is needed in this area.

Wheeled Vehicles on Coarse-Grained Soils

Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils

The *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, and predicted performance information. The vehicle configuration characteristics include the tire deflection, tire stiffness factor, tire width, tire diameter, and the average wheel load. The measured soil characteristics are the soil gradient (G) and the respective CI, where CI was computed from G using the relation CI=3.5G as demonstrated in Appendix A of T.R. No. 3-666 Report 8 (Turnage 1972). The measured performance information is the measured drawbar pull coefficient. The predicted performance information is the powered-wheel/sand numeric (Π_P) and the NRMM II predicted drawbar pull coefficient. Other prediction information is included in the database that is not part of NRMM II, but it was only included for comparative purposes.

Though nominal slip for the Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils relationship in NRMM II is 15%, the database contains only drawbar at 20% slip (D/W_{20}) and drawbar at maximum-pull slip (D/W_{MP}) data. The D/W_{20} and D/W_{MP} data can be used to evaluate the relationship because wheeled vehicles in sand typically obtain maximum pull in the range from 15% to 30% slip (Jones 1992). This means that D/W values would not be significantly different in magnitude regardless of whether the data were based on 15%, 20%, or maximum-pull slip.

The *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database is a modified version of a database developed during previous stochastic vehicle mobility forecasting efforts. The original database was obtained, and the organization was slightly modified. The data contents were not added to nor were any of the data "rejected". The database content was assumed adequate.

One source, T.R. No. 3-666 Report 8, was investigated for the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database. The data used were those presented in tables 11 and 12 of Report 8. Table 11 contained D/W_{20} data from controlled laboratory testing on prepared Yuma sand. Table 12 contained D/W_{MP} data from field testing on coarse-grained soils from 1958 to 1961 that were previously presented in the 17th Supplement of T.M. No. 3-240 (Rush 1963). All of the testing involved wheeled vehicles that were standard in the nineteen fifties, sixties, and early seventies.

There are some available sources that were not investigated primarily due to time constraints. The Wheeled versus Tracked Program generated some data involving SP-SM soils, with and without simulated rainfall, and involving wheeled vehicles standard in the nineteen eighties and today. Also, there were reports published in the nineteen sixties dealing with trafficability testing of coarse-grained soils that might contain some useful data. There were reports published from the nineteen seventies through recent years that also contain data from testing on coarse-grained soils. A fairly large amount of testing was conducted in Yuma, AZ with wheeled vehicles just prior to Desert Shield/Desert Storm. If these additional sources were investigated, it is probable that the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database could be significantly improved in terms of applicability for evaluation of the relationship's variability and also for possible improvements to the relationship.

Table 24 lists the vehicles and test locations associated with the data contained in the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database. To prevent the table from being unnecessarily long, the many different tire pressure, i.e. tire deflection, configurations are not listed. A scatter plot of the measured data with the NRMM II prediction curve is shown on Plate 66. In generating this scatter plot, it was necessary to adjust the measured data by adding X_{TS} to $D/W_{Nom.}$ and consider the soil strength correction factor for multiple assembly passes negligible. The plate indicates that this database is adequate for evaluation of the variability in the relationship. The plate also indicates that some attention needs to be given to the modeling of drawbar for wheeled vehicles on coarse-grained soils.

Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils

The *Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration characteristics include tire type, tire pressure, a tire construction flag (bias or radial), tire section width, tire section height, tire diameter, tire deflection, total number of tires, GVW, and the tire stiffness factor (X_{TS}). The measured soil characteristics include the test location, test site, soil surface condition (simulated rainfall amount), and 0-6 inch CI. The measured performance information consists of the drawbar pull, D/W, and slip. The data background information provides the test date, the primary reference source, and data remarks. The predicted performance information is the powered-wheel/sand numeric (Π_P) and the NRMM II predicted slip.

Two sources were investigated for the *Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database: (1) Historical files on the AMC-71 Validation Program (Schreiner and Willoughby 1976), and (2) T.R. GL-92-7 (Jones 1992). The data primarily involve testing on SP-SM, SP, or SW soils, but they also involve testing on arid SM soils and desert pavement material. The data involve testing on high CI soils with measured CI ranging from 489 to 600 as well as data from testing on low CI soils with measured CI ranging from 34 to 149. None of the investigated data were "rejected", but there are several other available sources that were not investigated due to time constraints. These additional sources were discussed in the previous section on the *Wheeled Vehicle Draw-*

bar at Nominal Slip on Coarse-Grained Soils database. If these additional sources were investigated, it is possible that the *Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database could be improved in terms of adequacy for evaluation of relationship variability and also for possible improvements to the relationship.

Table 25 lists the vehicle configurations and respective sources contained in the *Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database. A scatter plot of the measured data with the NRMM II prediction curve is shown on Plate 67. In generating this scatter plot, it was necessary to adjust the measured data by adding Δ to D/W. This shifted all of the measured data up to the magnitude of the single prediction curve. This adjustment was done in accordance with the modeling hypothesis that the slip curve can be shifted, but in order to present only one plot, the data were instead shifted to the curve. The plate indicates that this database is adequate for evaluation of the variability in the relationship. The plate also indicates that some attention needs to be given to the modeling of slip for wheeled vehicles on coarse-grained soils.

Wheeled Vehicle Motion Resistance on Coarse-Grained Soils

The *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database contains vehicle configuration characteristics, measured soil characteristics, measured performance information, and predicted performance information. The vehicle configuration characteristics include the tire deflection, tire stiffness factor, tire width, tire diameter, and average wheel load. The measured soil characteristics are the soil gradient (G) and the respective CI, where CI was computed from G using the relation CI=3.5G as demonstrated in Appendix A of T.R. No. 3-666 Report 8. The measured performance information is the measured motion resistance coefficient. The predicted performance information is the unpowered-wheel/sand numeric (Π_U) and the NRMM II predicted motion resistance coefficient. Other prediction information is included in the database that is not part of NRMM II, but it was only included for comparative purposes.

The *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database is a modified version of a database developed during previous stochastic vehicle mobility forecasting efforts. The original database was obtained, and the organization was slightly modified. The data contents were not added to nor were any of the data "rejected". The database content was assumed adequate.

One source was investigated for the *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database: T.R. No. 3-666 Report 8. The data used were those presented in table 13 of Report 8. This table contains data from testing on coarse-grained soils from 1958 to 1961, and these data were previously presented in the 17th Supplement of T.M. No. 3-240. These data came from field testing of wheeled vehicles that were standard in the nineteen fifties, sixties, and early seventies. Sources that are available but were not investigated were mentioned in the previous section on the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database. If these additional sources were investigated, it is possible that the *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database could be improved in terms of adequacy for evaluation of relationship's variability and also for possible improvements to the relationship.

Table 26 lists the vehicles and test locations associated with the data contained in the *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database. To prevent the table from being unnecessarily long, the many different tire pressure, i.e. tire deflection, configurations are not listed. A scatter plot of the measured data with the NRMM II prediction curve is shown on Plate 68. In generating this scatter plot, it was necessary to adjust the measured data by subtracting X_{TS} from R/W and consider the soil strength correction factor for multiple assembly passes negligible. The plate indicates that this database is adequate for evaluation of the variability in the relationship. The plate also indicates that some attention needs to be given to the modeling of motion resistance for wheeled vehicles on coarse-grained soils.

Vehicles on Muskeg

Muskeg One-Pass Vehicle Cone Index

The *Muskeg One-Pass Vehicle Cone Index* database contains vehicle configuration characteristics, data background information, measured performance information, and predicted performance information. The vehicle configuration characteristics include the GVW, tire section width, tire outside diameter, number of tires, track width, and track length on ground. The primary reference source provides the data background information. The measured performance information is the measured Muskeg VCI_1. The predicted performance information is the NRMM II predicted Muskeg VCI_1.

Six published sources were investigated for the *Muskeg One-Pass Vehicle Cone Index* database:

(1) M.P. No. 4-438 (Rush 1961),
(2) T.R. No. 3-656 Report 1 (Radforth and Rush 1964),
(3) T.R. No. 3-656 Report 2 (Rush, Schreiner, and Radforth 1965),
(4) T.R. No. 3-744 (Rush and Schreiner 1966),
(5) "A Technique for Estimating the Performance of Tracked Vehicles in Muskeg" (Schreiner 1967), and
(6) M.P. M-74-1 (Willoughby 1974).

The primary source investigated for the performance information was a Muskeg File maintained in the MSD historical files. This file contains most of the work done in the development of all the Muskeg Traction relationships. All of the measured Muskeg VCI_1 values were obtained from the Muskeg File, and the applicable published sources were used to obtain the complementary information such as vehicle configuration information.

M.P. No. 4-438 was not used because it involved 50-Pass VCI testing from which the VCI_1 value was not obtainable. M.P. M-74-1 was not used either because the VCI_1 value was not obtainable.

Some of the necessary information for the wheeled vehicle configuration characteristics was not available. No published source could be located that reported wheeled vehicle performance, and it is probable that no such report was ever published at WES. All but two of the vehicles were already characterized in vehicle-files maintained at MSD, and these vehicle-files were used. The Landrover and Iron Mule had no vehicle-files, and the only information available for them was CPF, W/P (weight over nominal contact perimeter), and GVW values written on analysis sheets in the Muskeg File. The CPF and W/P values are both computed using nominal tire section width (b) and nominal tire diameter (d), the main two missing characteristics needed to compute the Muskeg VCI_1 values. Therefore, b and d were computed for these two vehicles from the CPF and W/P values using the two equations shown below with two unknowns, **b** and **d**.

$$CPF = \frac{2W}{ndb} \qquad \frac{W}{P} = \frac{W}{2n(d+b)}$$

Most of the database entries do not contain definite measured VCI_1 values, but instead contain entries for the measured Lowest GO CI. These Lowest GO entries come from tests in which no NOGO points were obtained, but this does not necessarily mean that the VCI_1 for these vehicles would be less than the Lowest GO CI. The measured VCI_1 entry in the database for these vehicles contains a less than symbol (<) in front of the Lowest GO CI value. These Lowest GO points were entered because the multi-pass test data associated with all of these points were used to help establish the Muskeg VCI_1 prediction relationships. These points should help estimate the variability common to the Muskeg VCI_1 relationships.

Tables 27 and 28 lists the vehicle configurations and respective data sources contained in the *Muskeg One-Pass Vehicle Cone Index* database. Scatter plots of the measured data with the NRMM II prediction curves are shown on Plates 69 and 70. For the purpose of creating these plates, the W/P terms for the vehicles have been back-calculated from the Vehicle $VCI_{1(MK)}$ values output from the Combination VCI Routine. The plates indicate that these databases are adequate for a conjectural evaluation of the variability in the relationships.

Muskeg Drawbar at Nominal Slip

The *Muskeg Drawbar at Nominal Slip* database contains vehicle configuration information, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration information includes a traction assembly type flag (wheeled or tracked), GVW, tire/track size, CPF, and NRMM II predicted Muskeg VCI_1. The measured soil characteristics are

USCS soil type and 0-6 inch CI. The measured performance information is drawbar pull coefficient and slip. The primary reference source and a data comment provide data background information. The predicted performance information consists of the 0-6 inch CI_X and the corresponding NRMM II predicted drawbar pull coefficient.

Three published sources were used to develop the *Muskeg Drawbar at Nominal Slip* database:

(1) T.R. No. 3-656 Report 1,
(2) T.R. No. 3-656 Report 2, and
(3) T.R. No. 3-744.

Another source used was the Muskeg File mentioned in the previous section on the *Muskeg One-Pass Vehicle Cone Index* database. All of the performance data were obtained from of the Muskeg File, and the applicable published sources were used to obtain the complementary information such as vehicle configuration information.

Table 29 lists the vehicle configurations and respective data sources contained in the *Muskeg Drawbar at Nominal Slip* database. Scatter plots of the measured data with the NRMM II prediction curves are shown on Plates 71 and 72. The plates indicate that these databases are adequate for a conjectural evaluation of the variability in the relationships. The plates also indicate that some attention needs to be given to the modeling of drawbar for vehicles on muskeg. More testing is needed in this area.

Muskeg Slip at "Maximum" Soil Strength

Though some data are available in the Muskeg File, no database was developed for the Muskeg Slip at "Maximum" Soil Strength empirical relationships. The available data involve both wheeled and tracked vehicles tested on muskeg, but only scatter plots of the data exist, i.e. the data coordinates are not tabulated. The time necessary to obtain the data from the scatter plots was not feasible with the existing time constraints. Another reason this database was not developed is the fact that the variability of the Muskeg Slip at "Maximum" Soil Strength relationships could be assumed similar to that of the Fine-Grained Slip at "Maximum" Soil Strength relationships. This assumption would probably result in variability characterizations as good as, if not better than, an analysis of the limited existing data.

Muskeg Motion Resistance

The *Muskeg Motion Resistance* database contains vehicle configuration information, measured soil characteristics, measured performance information, data background information, and predicted performance information. The vehicle configuration information includes a traction assembly type flag (wheeled or tracked), GVW, tire/track size, CPF, and NRMM II predicted Muskeg VCI_1. The measured soil characteristics are USCS soil type and 0-6 inch CI. The measured performance information is the motion resistance coefficient. The primary reference source and a data comment provide data background information. The predicted performance information consists of the 0-6 inch CI_X and the corresponding NRMM II predicted motion resistance coefficient.

The sources investigated for the *Muskeg Motion Resistance* database are the same as those investigated for the *Muskeg Drawbar at Nominal Slip* database. As was done in all of the data gathering for the muskeg traction relationships, the available performance data were obtained from the Muskeg File, and the published sources were used to obtain the complimentary information.

Table 30 lists the vehicle configurations and respective data sources contained in the *Muskeg Motion Resistance* database. A scatter plot of the measured data with the NRMM II prediction curve is provided on Plate 73. The plate indicates that this database is adequate for a conjectural evaluation of the variability in the relationship. The plate also indicates that some attention needs to be given to the modeling of motion resistance for vehicles on muskeg. More testing is needed in this area.

4 Conclusions and Recommendations

Conclusions

Based on the research conducted in this database developing effort, the following conclusions are made:

a. The current NRMM II Fine-Grained Drawbar at Nominal Slip empirical relationships have excessively conservative prediction equations.

b. The Drawbar at Nominal Slip relationships can be evaluated using measured data that are based on any slip, not just the set nominal slip. This is accomplished by using the NRMM modeling hypothesis that the Drawbar at Nominal Slip relationships can be shifted from one slip magnitude to another based on the shape of their respective Slip at "Maximum" Soil Strength relationships.

c. When segregated according to "Vehicle-Type" or "Tire-Deflection-Class", the database for the Fine-Grained Drawbar at Nominal Slip empirical relationships does not facilitate better prediction equations nor create reduced variability.

d. There are no available, applicable data to support MR18. It appears that MR18 was extrapolated from MR07 (the non-slippery version of MR18) based on the typical change in R/W from the non-slippery to the slippery surface condition of the other Fine-Grained Motion Resistance empirical relationships.

e. The logic behind using MR08 and MR09, which were developed using the Numeric Methodology, to predict motion resistance for unpowered assemblies while using the other 18 relationships, which were developed using the VCI_1 Methodology, to predict motion resistance for powered assemblies is not apparent. All 20 of these relationships were developed using towed motion resistance test data (i.e. unpowered). Also, the specific data used to develop MR08 and

MR09 were also used to develop some of the other 18 relationships.

f. The databases for the Vehicles on Fine-Grained Soils VTI category are adequate for at least a conjectural evaluation of the variability in all of the empirical relationships except ER22, MR06, MR11, MR16, MR17, MR18, MR08, and MR09.

g. The databases for the Tracked Vehicles on Coarse-Grained Soils VTI category are adequate for at least a conjectural evaluation of the variability in all of the empirical relationships.

h. Some attention needs to be given to the modeling of Tracked Vehicle Traction on Coarse-Grained Soils in the areas of drawbar and motion resistance. More testing is needed in these areas.

i. The databases for the Wheeled Vehicles on Coarse-Grained Soils VTI category are adequate for at least a conjectural evaluation of the variability in all of the empirical relationships.

j. Some attention needs to be given to the modeling of Wheeled Vehicle Traction on Coarse-Grained Soils.

k. The databases for the Vehicles on Muskeg VTI category are adequate for a conjectural evaluation of the variability in all of the empirical relationships except MK_S1 and MK_S2.

l. Some attention needs to be given to the modeling of Vehicle Traction on Muskeg in the areas of drawbar, slip, and motion resistance. More testing is needed in these areas.

Recommendations

Based on the conclusions drawn from this research, the following recommendations are made:

a. The proposed new prediction equations for the Vehicle Traction on Fine-Grained Soils empirical relationships should be implemented into NRMM.

b. The variability in the Fine-Grained Drawbar at Nominal Slip empirical relationships should be evaluated using primarily the data in the 20% Slip databases and hence using the shifted prediction equations. Higher quality test data are obtained at the 20% slip condition than at the current nominal slip condition (100% slip).

c. MR08 and MR09 should be abolished, and the modeling assumption should be made that R/W is the same for powered and unpowered wheeled assemblies (as was done for tracked assemblies). The intent of this recommendation is not to imply that the VCI_1 Methodology should be used over the Numeric Methodology. The intent is to abandon some questionable logic.

d. The variability in ER22 should be deduced from the evaluated variability in the other Fine-Grained Slip at "Maximum" Soil Strength empirical relationships with similar relationship criteria.

e. The variability in MR06, MR11, MR16, MR17, and MR18 should be deduced from the evaluated variability in the other Fine-Grained Motion Resistance empirical relationships with similar relationship criteria.

f. A small-scale test program needs to be designed for improvements in NRMM modeling of Tracked Vehicle Traction on Coarse-Grained Soils. This would involve drawbar pull - slip and towed motion resistance testing on predetermined cone index ranges.

g. The variability in MK_S1 and MK_S2 should be deduced from the evaluated variability in the Fine-Grained Slip at "Maximum" Soil Strength empirical relationships focusing on those with the largest variability.

h. A small-scale test program needs to be designed for improvements in NRMM modeling of Vehicle Traction on Muskeg. This would involve drawbar pull - slip and towed motion resistance testing on predetermined cone index ranges.

i. The databases developed during this research should be expanded so they can be used for improvements in the NRMM traction modeling relationships. The expansion would involve entering all of the vehicle characteristics proven to influence vehicle traction into the databases. Improved relationships could then be developed by conducting a rigorous analysis with the databases for investigation of new traction relationships that have less variability, are more theoretical in nature, and are more practicable for vehicle design.

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Table 1
NRMM II Fine-Grained One-Pass Vehicle Cone Index Empirical Relationships

Relationship Description				Prediction Equation [a]
Criteria			Name	
Wheeled	Powered or Braked	MI ≤ 115 psi	VCI1FGW1	$VCI_{1(FG)} = \left(11.48 + 0.2\,MI - \frac{39.2}{MI + 3.74}\right)\left[\frac{0.15}{\delta/h}\right]^{0.25}$ [b]
		MI > 115 psi		$VCI_{1(FG)} = (4.1\,MI^{0.446})\left[\frac{0.15}{\delta/h}\right]^{0.25}$ [b]
	Unpowered and Unbraked		Not Applicable	A Numeric prediction system is used for Unpowered Wheeled Axles. Therefore, no VCI_1 value is needed.
Tracked			VCI1FGT1	$VCI_{1(FG)} = \left(7.0 + 0.2\,MI - \frac{39.2}{MI + 5.6}\right)$ [b]

[a] The Prediction Equations are used for each individual traction assembly and, if applicable, at each tire deflection scenario, δ/h. The $VCI_{1(FG)}$ values for all of the assemblies are then integrated in the Combination VCI routine to obtain a single $VCI_{1(FG)}$ for the vehicle. The Combination VCI routine uses predicted drawbar and predicted motion resistance with the predicted $VCI_{1(FG)}$ values for each assembly to establish the Vehicle $VCI_{1(FG)}$ value.

It should be noted that the Vehicle $VCI_{1(FG)}$ is computed primarily to serve as a relative indicator of vehicle performance, i.e. it is not used in the NRMM II algorithms for predicting drawbar or motion resistance.

[b] The Mobility Index (MI) is an empirical parameter composed of many traction influencing vehicle characteristics. It is computed differently for wheeled vehicles than for tracked vehicles. For specific information on how to compute MI, refer to paragraph no. 59 beginning on page 32 of Technical Report GL-92-19 (Ahlvin and Haley 1992).

Table 2
Soil Groups for NRMM II Fine-Grained Traction

Soil Group (SG) Reference No.	USCS Soil Types in the Soil Group
1	SC GC
2	CH MH OH
3	ML ML-CL CL OL
4	SM SM-SC GM GM-GC
5	Rock

Table 3
NRMM II Fine-Grained Drawbar at Nominal Slip Empirical Relationships

Relationship Description: Criteria				Name	Prediction Equation [a]
Wheeled	w/out Tire Chains	CPF ≥ 4 psi	SM	ER01	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.5200142 - \frac{4.558500}{RCI_X + 8.177059} + 0.03746007$
			SC, ML & CL	ER02(A)	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6152356 - \frac{6.183363}{RCI_X + 9.258565} + 0.05261765$
			CH	ER02(B)	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6152356 - \frac{6.183363}{RCI_X + 9.258565} + 0.05261765$
		CPF < 4 psi		ER03	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6452267 - \frac{5.036329}{RCI_X + 7.350470} + 0.03994437$
	w/ Tire Chains			ER04	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6452267 - \frac{5.036329}{RCI_X + 7.350470} + 0.03994437$
Tracked	CPF ≥ 4 psi		ML, CL & SM	ER05	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6512633 - \frac{4.906830}{RCI_X + 7.285463} + 0.02224646$
			SC & CH	ER06	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.6989994 - \frac{5.131209}{RCI_X + 6.992280} + 0.03483978$
	CPF < 4 psi			ER07	$\left(\frac{D}{W}\right)^{RCI}_{Nom} = 0.7241738 - \frac{4.838035}{RCI_X + 6.301396} + 0.04359810$

[a] The Prediction Equations are used for each individual traction assembly. The D/W values for all of the assemblies are then integrated in a force summing routine to obtain a single D/W value for the combination vehicle.

Table 4
NRMM II Empirical Relations for Fine-Grained SLIP at "Maximum" Soil Strength and "Non-slippery" Surface Conditions

Relationship Description					Prediction Equation [a]
Criteria				Name	
Wheeled	w/out Tire Chains	CPF ≥ 4 psi	SM	ER08	$SLIP^{\text{"}Max\text{"}} = \frac{-0.02739573}{\frac{D}{W} - 0.5852786} - 0.04432457$
			SC, ML & CL	ER09	$SLIP^{\text{"}Max\text{"}} = \frac{-0.03667018}{\frac{D}{W} - 0.7223892} - 0.04782123$
			CH	ER10	$SLIP^{\text{"}Max\text{"}} = \frac{-0.04857868}{\frac{D}{W} - 0.7763966} - 0.06025273$
		CPF < 4 psi		ER11	$SLIP^{\text{"}Max\text{"}} = \frac{-0.03184062}{\frac{D}{W} - 0.7675019} - 0.03507795$
	w/ Tire Chains			ER12	$SLIP^{\text{"}Max\text{"}} = \frac{-0.03184062}{\frac{D}{W} - 0.7675019} - 0.03507795$
Tracked	CPF ≥ 4 psi		ML, CL & SM	ER13	$SLIP^{\text{"}Max\text{"}} = \frac{-0.03180914}{\frac{D}{W} - 0.7674085} - 0.03503627$
			SC & CH	ER14	$SLIP^{\text{"}Max\text{"}} = \frac{-0.02848516}{\frac{D}{W} - 0.7976395} - 0.02962196$
	CPF < 4 psi			ER15	$SLIP^{\text{"}Max\text{"}} = \frac{-0.04084762}{\frac{D}{W} - 0.8591338} - 0.04495945$

[a] The Prediction Equations are used for the combination vehicle, i.e. predictions are not made per assembly.

Table 5
NRMM II Empirical Relations for Fine-Grained SLIP at "Maximum" Soil Strength and "Slippery" Surface Conditions (≥ ¼" rainfall)

Relationship Description					Prediction Equation [a]
Criteria				Name	
Wheeled	w/out Tire Chains		CH	ER16	$SLIP^{\text{"Max"}} = \frac{-0.06132906}{\frac{D}{W} - 0.3625492} - 0.1665583$
			SM	ER17	$SLIP^{\text{"Max"}} = \frac{-0.05018879}{\frac{D}{W} - 0.3670227} - 0.1372441$
			SC	ER18	$SLIP^{\text{"Max"}} = \frac{-0.08263566}{\frac{D}{W} - 0.4527318} - 0.1840957$
			ML & CL	ER19	$SLIP^{\text{"Max"}} = \frac{-0.03632374}{\frac{D}{W} - 0.4526733} - 0.07847599$
	w/ Tire Chains		CH	ER20	$SLIP^{\text{"Max"}} = \frac{-0.1623461}{\frac{D}{W} - 0.6357296} - 0.25022900$
			ML, CL & SM	ER21	$SLIP^{\text{"Max"}} = \frac{-0.1314272}{\frac{D}{W} - 0.7230009} - 0.1771455$
			SC	ER22	$SLIP^{\text{"Max"}} = \frac{-0.1392698}{\frac{D}{W} - 0.7618129} - 0.1824433$
Tracked	CPF ≥ 4 psi	w/ Pads	CH	ER23	$SLIP^{\text{"Max"}} = \frac{-0.04488859}{\frac{D}{W} - 0.3554742} - 0.1236756$
			SC	ER24	$SLIP^{\text{"Max"}} = \frac{-0.04226002}{\frac{D}{W} - 0.4201221} - 0.09864486$
			ML & CL	ER25	$SLIP^{\text{"Max"}} = \frac{-0.03116685}{\frac{D}{W} - 0.4656324} - 0.06553027$
			SM	ER26	$SLIP^{\text{"Max"}} = \frac{-0.04009845}{\frac{D}{W} - 0.5084050} - 0.07816798$
		w/out Pads	CH	ER27	$SLIP^{\text{"Max"}} = \frac{-0.04796802}{\frac{D}{W} - 0.5371075} - 0.08904103$
			ML & CL	ER28	$SLIP^{\text{"Max"}} = \frac{-0.02846953}{\frac{D}{W} - 0.6321998} - 0.04257004$
			SC & SM	ER29	$SLIP^{\text{"Max"}} = \frac{-0.01721540}{\frac{D}{W} - 0.6596302} - 0.02557627$
	CPF < 4 psi		SC & CH	ER30	$SLIP^{\text{"Max"}} = \frac{-0.03444016}{\frac{D}{W} - 0.5808066} - 0.05720393$
			ML, CL & SM	ER31	$SLIP^{\text{"Max"}} = \frac{-0.07362948}{\frac{D}{W} - 0.7834008} - 0.09228875$

[a] The Prediction Equations are used for the combination vehicle, i.e. predictions are not made per assembly.

Table 6
NRMM II Empirical Relations for Fine-Grained Motion Resistance in "Non-slippery" Surface Conditions

Relationship Description: Criteria					Name	Prediction Equation [a]
Wheeled	Powered	CPF ≥ 4 psi	Radial Tires	SC & CH	MR01	$\frac{R}{W}^{RCI} = 0.042 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF ≥ 4 psi	Radial Tires	ML & CL	MR02	$\frac{R}{W}^{RCI} = 0.035 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF ≥ 4 psi	Radial Tires	SM	MR03	$\frac{R}{W}^{RCI} = 0.060 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF ≥ 4 psi	Bias Tires	SC & CH	MR04	$\frac{R}{W}^{RCI} = 0.045 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF ≥ 4 psi	Bias Tires	ML & CL	MR05	$\frac{R}{W}^{RCI} = 0.038 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF ≥ 4 psi	Bias Tires	SM	MR06	$\frac{R}{W}^{RCI} = 0.063 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
Wheeled	Powered	CPF < 4 psi			MR07	$\frac{R}{W}^{RCI} = 0.035 + \frac{0.8610}{RCI_X + 3.249} - \frac{RCI_X}{75000}$
Wheeled	Unpowered			β > 1.90556 [b]	MR08	$\frac{R}{W}^{RCI} = 0.04 + \frac{0.2}{\beta - 1.35}$
Wheeled	Unpowered			β ≤ 1.90556 [b]	MR08	$\frac{R}{W}^{RCI} = 1.0 - 0.314868\,\beta$
Tracked				CH, SC, ML & CL	MR10	$\frac{R}{W}^{RCI} = 0.052 + \frac{2.3075}{RCI_X + 6.500}$
Tracked				SM	MR11	$\frac{R}{W}^{RCI} = 0.062 + \frac{2.3075}{RCI_X + 6.500}$

[a] The Prediction Equations are used for each individual traction assembly. The R/W values for all of the assemblies are then integrated in a force summing routine to obtain a single R/W value for the combination vehicle.

[b] The wheel/clay numeric (β), as implemented in NRMM II, is computed as follows:

$$\beta = \frac{RCI\,b\,d}{\frac{W}{n}\left(1 + \frac{b}{2d}\right)}\sqrt{\frac{\delta}{h}}$$

Table 7
NRMM II Empirical Relations for Fine-Grained Motion Resistance in "Slippery" Surface Conditions (≥ ¼" rainfall)

Relationship Description						Prediction Equation [a]
Criteria					Name	
Wheeled	Powered	CPF ≥ 4 psi	Radial Tires	SC & CH	MR12	$\left(\frac{R}{W}\right)^{RCI} = 0.050 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
				ML & CL	MR13	$\left(\frac{R}{W}\right)^{RCI} = 0.037 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
				SM	MR14	$\left(\frac{R}{W}\right)^{RCI} = 0.066 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
			Bias Tires	SC & CH	MR15	$\left(\frac{R}{W}\right)^{RCI} = 0.053 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
				ML & CL	MR16	$\left(\frac{R}{W}\right)^{RCI} = 0.040 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
				SM	MR17	$\left(\frac{R}{W}\right)^{RCI} = 0.069 + \frac{2.3075}{RCI_X + 6.500} - \frac{RCI_X}{40000}$
		CPF < 4 psi			MR18	$\left(\frac{R}{W}\right)^{RCI} = 0.044 + \frac{0.8610}{RCI_X + 3.249} - \frac{RCI_X}{75000}$
	Unpowered			$\beta > 1.90556$ [b]	MR09	$\left(\frac{R}{W}\right)^{RCI} = 0.04 + \frac{0.2}{\beta - 1.35}$
				$\beta \le 1.90556$ [b]		$\left(\frac{R}{W}\right)^{RCI} = 1.0 - 0.314868\,\beta$
Tracked				CH, SC, ML & CL	MR19	$\left(\frac{R}{W}\right)^{RCI} = 0.062 + \frac{2.3075}{RCI_X + 6.500}$
				SM	MR20	$\left(\frac{R}{W}\right)^{RCI} = 0.075 + \frac{2.3075}{RCI_X + 6.500}$

[a] The Prediction Equations are used for each individual traction assembly. The R/W values for all of the assemblies are then integrated in a force summing routine to obtain a single R/W value for the combination vehicle.

[b] The wheel/clay numeric (β), as implemented in NRMM II, is computed as follows:

$$\beta = \frac{RCI\,b\,d}{\frac{W}{n}\left(1 + \frac{b}{2d}\right)}\sqrt{\frac{\delta}{h}}$$

Table 8
NRMM II Empirical Relations for Tracked Vehicle Traction on Coarse-Grained Soils

Relationship Description				Prediction Equation [a]
Parameter	Criteria		Name	
$\frac{D}{W}^{CI}_{Nom.}$	Flexible	$\Pi_T > 11.29$ [b]	CGTDF1	$\frac{D}{W}^{CI}_{Nom.} = 0.3926$
		$\Pi_T \le 11.29$ [b]		$\frac{D}{W}^{CI}_{Nom.} = \frac{D}{W}\left(\Pi_T\right)$ [c]
	Girderized	$\Pi_T > 64.85$ [b]	CGTDG1	$\frac{D}{W}^{CI}_{Nom.} = 0.5365$
		$\Pi_T \le 64.85$ [b]		$\frac{D}{W}^{CI}_{Nom.} = \frac{D}{W}\left(\Pi_T\right)$ [c]
$SLIP^{\text{"}Max\text{"}}$	Flexible		CGTSF1	$SLIP^{\text{"}Max\text{"}} = \frac{0.1111\frac{D}{W}}{0.62222 - \frac{D}{W}} + 0.01$
	Girderized		CGTSG1	$SLIP^{\text{"}Max\text{"}} = \frac{0.02857\frac{D}{W}}{0.61714 - \frac{D}{W}} + 0.01$
$\frac{R}{W}^{CI}$	Flexible		CGTRF1	$\frac{R}{W}^{CI} = 0.145$
	Girderized		CGTRG1	$\frac{R}{W}^{CI} = 0.119$

[a] The D/W and the R/W relations are used per assembly. The Slip relations are used per vehicle.

[b] The track/sand numeric, as implemented in NRMM II, is computed as follows:

$$\Pi_T = 0.6\left(\frac{0.8645}{3.0}\,CI\right)\frac{(bl)^{3/2}}{\frac{1}{2}W}$$

[c] The empirical relationships for predicting D/W as a function of the track/sand numeric are as follows:

$$\frac{D}{W}\left(\Pi_T\right) = 0.121 + 0.258\,LOG(\Pi_T) \qquad 0 < \Pi_T \le 25$$

$$\frac{D}{W}\left(\Pi_T\right) = 0.339 + 0.109\,LOG(\Pi_T) \qquad 25 < \Pi_T \le 100$$

$$\frac{D}{W}\left(\Pi_T\right) = 0.481 + 0.038\,LOG(\Pi_T) \qquad 100 < \Pi_T \le 1000$$

$$\frac{D}{W}\left(\Pi_T\right) = 0.595 \qquad \Pi_T > 1000$$

Table 9
NRMM II Empirical Relations for Wheeled Vehicle Traction on Coarse-Grained Soils

Relationship Description			Prediction Equation [a]
Parameter	Criteria	Name	
$\frac{D}{W}^{CI}_{Nom.}$	All Wheeled	CGWD1	$\frac{D}{W}^{CI}_{Nom.} = 0.52 - \frac{396.0}{\Pi_P + 557.0} - X_{TS}$ [b, c]
$SLIP^{\text{"Max"}}$	All Wheeled	CGWS1	$SLIP^{\text{"Max"}} = 0.15 - \sqrt{0.0225 - 0.04326 \frac{D}{W}}$
$\frac{R}{W}^{CI}$	All Wheeled	CGWR1	$\frac{R}{W}^{CI} = 0.44 - 0.002287\,\Pi_U + \sqrt{(0.44 - 0.002287\,\Pi_U)^2 + 0.0000457\,\Pi_U + 0.08} + X_{TS}$ [b, c]

[a] The D/W and the R/W relations are used per assembly. The Slip relations are used per vehicle.

[b] The powered-wheel/sand numeric (Π_P) and the unpowered-wheel/sand numeric (Π_U), as implemented in NRMM II, are computed as follows:

$$\Pi_P = CI\left[\frac{(bd)^{3/2} n}{(1 - \delta/h)^3\, W}\right] SS_{CF}$$

$$\Pi_U = \frac{\Pi_P}{1 - \frac{b}{d}}$$

SS_{CF} = Soil Strength Correction Factor for multiple assembly passes. It can be assumed equal to 1.0 with negligible effects for typical all-drive wheeled vehicles. For more specific information, refer to page 37 of Technical Report GL-92-19 (Ahlvin and Haley 1992).

[c] The tire stiffness factor (X_{TS}), as implemented in NRMM II, is computed as follows:

"flexible" tires (typically used for radial tires) $X_{TS} = 0.05\left(\frac{\delta}{h}\right)$

"medium" tires (typically used for bias tires) $X_{TS} = 0.2\left(\frac{\delta}{h}\right)^{1.4}$

"stiff" tires (typically used for solid tires) $X_{TS} = 0.4\left(\frac{\delta}{h}\right)^{1.6}$

Table 10
NRMM II Muskeg Traction Empirical Relationships

Relationship Description			Prediction Equation [a]
Parameter	Criteria	Name	
$VCI_{1(MK)}$	Wheeled	MK_VW1	$VCI_{1(MK)} = 13.0 + 0.535\left[\frac{W}{P}\right]$ [b]
	Tracked	MK_VT1	$VCI_{1(MK)} = 13.0 + 0.0625\left[\frac{W}{P}\right]$ [c]
$\frac{D}{W}^{CI}_{Nom.}$	Wheeled ; Tracked w/ CPF ≥ 4 psi	MK_D1	$\frac{D}{W}^{CI}_{Nom.} = 0.3537 + 0.02258 CI_X - \sqrt{(0.3537 + 0.02258 CI_X)^2 - 0.03071 CI_X}$
	Tracked w/ CPF < 4 psi	MK_D2	$\frac{D}{W}^{CI}_{Nom.} = 0.5464 + 0.1091 CI_X - \sqrt{(0.5464 + 0.1091 CI_X)^2 - 0.192 CI_X}$
$SLIP^{\text{"Max"}}$	Wheeled ; Tracked w/ CPF ≥ 4 psi	MK_S1	$SLIP^{\text{"Max"}} = 0.1024\frac{D}{W} + \frac{0.01062}{0.7564 - \frac{D}{W}} - 0.00864$
	Tracked w/ CPF < 4 psi	MK_S2	$SLIP^{\text{"Max"}} = 0.0585\frac{D}{W} + \frac{0.01336}{0.9640 - \frac{D}{W}} - 0.01060$
$\frac{R}{W}^{CI}$	All Assemblies	MK_T1	$\frac{R}{W}^{CI} = 0.045 + \frac{2.3075}{CI_X + 6.5}$

[a] The VCI_1, D/W, and R/W relations are used per assembly. The Slip relations are used per vehicle.

[b] For wheeled vehicles on muskeg: $\frac{W}{P} = \left[\frac{W}{(b+d)n}\right]$

[c] For tracked vehicles on muskeg: $\frac{W}{P} = \left[\frac{W}{b+l}\right]$

Table 11
1994 Proposed New Prediction Curves for NRMM II Empirical Traction Relations

Relationship Description				Name	Prediction Equation
Criteria					
Proposed New Curves for Fine-Grained Drawbar at Nominal Slip					
Wheeled	w/out Tire Chains	CPF ≥ 4 psi	SM	ER01	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.6052632 - \frac{3.185596}{RCI_X + 5.263158}$
			SC, ML & CL	ER02(A)	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.7095197 - \frac{6.219728}{RCI_X + 8.220664}$
			CH	ER02(B)	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.7615758 - \frac{6.321873}{RCI_X + 7.613835}$
		CPF < 4 psi		ER03	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.7826192 - \frac{5.804033}{RCI_X + 6.799284}$
	w/ Tire Chains			ER04	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.7826192 - \frac{5.804033}{RCI_X + 6.799284}$
Tracked	CPF ≥ 4 psi		ML, CL & SM	ER05	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.7814494 - \frac{6.209946}{RCI_X + 7.854210}$
			SC & CH	ER06	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.8117813 - \frac{5.737010}{RCI_X + 6.507696}$
	CPF < 4 psi			ER07	$\frac{D}{W}{}^{RCI}_{Nom.} = 0.8476903 - \frac{4.974673}{RCI_X + 5.724387}$
Proposed New Curves for Fine-Grained SLIP at "Maximum" Soil Strength and "Non-Slippery" Surface Conditions					
Wheeled	w/out Tire Chains	CPF≥ 4 psi	SM	ER08	$SLIP^{\text{"}Max\text{"}} = \frac{-0.02642333}{\frac{D}{W} - 0.6253521} - 0.04225352$

Table 12
Vehicle Configurations and Sources contained in the *Fine-Grained One-Pass Vehicle Cone Index* Database

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
Wheeled Vehicle Configurations						
HETS M1070 w/M1000	425/95R20 XZL, TLR 215/75R17.5 XTA	40/90	-----	No	229300	MSD Files
TCM (Teledyne Continental Motors) MTV	395/85R20 Goodyear	32	-----	No	35070	MSD Files
TCM (Teledyne Continential Motors) LMTV	395/85R20 Goodyear	34	-----	No	22310	MSD Files
S&S (Stewart & Stevenson) MTV	395/85R20 Michelin	42	-----	No	35770	MSD Files
S&S (Stewart & Stevenson) LMTV	395/85R20 Michelin	36	-----	No	23385	MSD Files
TTC (Tactical Truck Corp) MTV	395/85R20 Goodyear	48	-----	No	35060	MSD Files
TTC (Tactical Truck Corp) LMTV	395/85R20 Goodyear	42	-----	No	23585	MSD Files
LAV 84	Michelin11.00R16 XL	52	-----	No	27100	MSD Files
LAV 84	Michelin 11.00R16 XL	29	-----	No	27100	MSD Files
M1008 CUCV	Armstrong 9.50x16.50 Bias	11.3	-----	No	6300	MSD Files
M1008 CUCV	Armstrong 9.50x16.50 Bias	38.3	-----	No	6300	MSD Files
M1008 CUCV	9.50R16.5 Radial	41.0	-----	No	6300	MSD Files
M1008 CUCV	9.50R16.5 Radial	14.5	-----	No	6300	MSD Files
FSU SA-8 Resupply Vehicle	1200x500-508 10PR Bias	14	-----	No	35780	TR GL-93-8
FSU SA-8 Resupply Vehicle	1200x500-508 10PR Bias	28	-----	No	35780	TR GL-93-8
ZIL-131	12.00-20	7	-----	No	21325	MP GL-91-8
ZIL-131	12.00-20	22	-----	No	21325	MP GL-91-8
ZIL-131	12.00-20	10	-----	No	21325	MP GL-91-8

Table 12 (Continued)

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
M35A2(mod.)	11.00x20 (singles)	20	-----	No	18225	MP GL-91-8
M35A2(mod.)	11.00x20 (singles)	13	-----	No	18225	MP GL-91-8
M35A1 6x6 2-1/2 Ton	11.00x20 (singles)	35.5	-----	No	19410	CR No. 3-152
M35A1 6x6 2-1/2 Ton	11.00x20 (singles)	13	-----	No	19410	CR No. 3-152
OSHKOSH PLS	425/95R20 XZL	16/22	-----	No	86255	MP GL-91-4
OSHKOSH PLS w/ PLS Trailer	425/95R20 XZL, TLR 15.5/80R20 G-20 XL	16/22, 40/30/30	-----	No	137235	MP GL-91-4
PACCAR PLS	17.5R25	42	-----	No	80655	MP GL-91-4
PACCAR PLS w/ PLS Trailer	17.5R25,TLR 445/65R22.5	42, 110	-----	No	127025	MP GL-91-4
GM PLS	425/95R20 XZL	42	-----	No	80795	MP GL-91-4
GM PLS w/ PLS Trailer	425/95R20 XZL, TLR 15.00x22.5	42, 65	-----	No	129735	MP GL-91-4
TATRA 813 (full Lockup)	15.00-21 TO	20/20	-----	No	50250	TR GL-90-3
TATRA 813 (full lockup)	15.00-21 TO	30/30	-----	No	50250	TR GL-90-3
TATRA 813 (differential slip)	15.00-21 TO	20/20	-----	No	50250	TR GL-90-3
TATRA 813 (differential slip)	15.00-21 TO	30/30	-----	No	50250	TR GL-90-3
FAMV	12.5R16.5 XL	30	-----	No	22690	TR GL-90-20
HML-ETU	20.5R25 Michelins	28/46, 66	-----	No	238600	TR GL-90-9
TRM 2000	12.5R20 XL	19/23	-----	No	13920	TR GL-90-1
5 TON TECH DEMO (singles)	14.00R20 XL	17	-----	No	32210	TR GL-89-9
M923A1 (singles)	14.00R20 XL	17	-----	No	32190	TR GL-89-9

Table 12 (Continued)

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
M923 (duals on rear)	11.00x20 NDCC Goodyear	60/30	-----	No	32485	TR GL-84-6
M923 (duals on rear)	11.00x20 NDCC Goodyear	25/25	-----	No	32485	TR GL-84-6
M923 (singles)	14.00R20 Michelin	30	-----	No	32260	TR GL-84-6
M923 (singles)	14.00R20 Michelin	10	-----	No	32260	TR GL-84-6
M923 (singles)	14.00R20 Goodyear	30	-----	No	32105	TR GL-84-6
M923 (singles)	14.00R20 Goodyear	10	-----	No	32105	TR GL-84-6
M923 (singles)	16.00R20 Michelin	25	-----	No	33585	TR GL-84-6
M923 (singles)	16.00R20 Michelin	8	-----	No	33585	TR GL-84-6
M923 (singles)	16.00R21 Goodyear	25	-----	No	33790	TR GL-84-6
M923 (singles)	16.00R21 Goodyear	8	-----	No	33790	TR GL-84-6
M1014 Tractor w/ XM986 GLCM TEL	16.00R20, TLR 18.00-22.5	50, 55	-----	No	79260	TR GL-87-17
M1014 Tractor w/ XM986 GLCM TEL	16.00R20, TRL 18.00-22.5	18, 24	-----	No	79260	TR GL-87-17
First Article Preproduction (SEE) Tractor	Michelin XL Radials	Not Avail.	-----	No	16170	TR GL-86-10
FAP 2026	15.00-21	44	-----	No	38620	TR GL-85-6
FAP 2026	15.00-21	13	-----	No	38620	TR GL-85-6
SISU A-45 w/FA303 Powered Trailer	NOKIA 14.5x20 MPT, TLR 18.00x19.5 SS	29/43, 30	-----	No	30395	MP GL-85-6
SISU A-45 w/FA303 Powered Trailer	NOKIA 14.5x20 MPT, TLR 18.00x19.5 SS	19/23, 18	-----	No	30395	MP GL-85-6
SISU A-45 w/FA303 Unpowered Trailer	NOKIA 14.5x20 MPT, TLR 18.00x19.5 SS	19/23, 18	-----	No	30395	MP GL-85-6
SISU A-45 w/FA303 Unpowered Trailer	NOKIA 14.5-20 MPT, TLR 18.00-19.5 SS	29/43, 30	-----	No	30395	MP GL-85-6
M985	16.00R20 XL	20/30	-----	No	62250	TR GL-85-4

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Table 12 (Continued)

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
M985	16.00R20 XL	20/20	-----	No	57770	TR GL-85-4
M985 w/M989 Trailer	16.00R20 XL, TLR 15.0-19.5	20/30, 85	-----	No	71190	TR GL-85-4
M985 w/M989 Trailer	16.00R20 XL, TLR 15.0-19.5	20/30, 85	-----	No	90820	TR GL-85-4
M977	16.00R20 XL	35/40	-----	No	60145	TR GL-85-4
M977	16.00R20 XL	20/30	-----	No	60145	TR GL-85-4
M977	16.00R20 XL	15/19	-----	No	60145	TR GL-85-4
M977	14.00x20	20/20	-----	No	56290	B.G.S. Black Book
M977	14.00x20	39/39	-----	No	56290	B.G.S. Black Book
M977	14.00x20	74/74	-----	No	56290	B.G.S. Black Book
M983 w/XM860A1 Semi-Trailer	16.00R20 XL, TLR 18.0x22.5	35/40, 55	-----	No	72656	TR GL-85-4
M983 w/XM860A1 Semi-Trailer	16.00R20 XL, TLR 18.0x22.5	20/20, 55	-----	No	72656	TR GL-85-4
Surrogate Fast Attack Vehicle (SFAV)	E78-15 NC / GY 31x11.50-15 Wrangler	18/20	-----	No	2750	TR GL-84-9
Surrogate Fast Attack Vehicle (SFAV)	E78-15 NC / GY 31x11.50-15 Wrangler	18/20	-----	No	3500	TR GL-84-9
M151 4x4 1/4 Ton	7.00x16 LW Bias	18/22	-----	No	3280	TR GL-84-9
M151 4x4 1/4 Ton	7.00x16	30	-----	No	3560	CR No. 3-152
M151 4x4 1/4 Ton	7.00x16	15	-----	No	3560	CR No. 3-152
M151 4x4 1/4 Ton	9.00x14	30	-----	No	3560	CR No. 3-152
M151 4x4 1/4 Ton	9.00x14	20	-----	No	3560	CR No. 3-152
M151 4x4 1/4 Ton	36x20-14R	15	-----	No	3560	CR No. 3-152
M151 4x4 1/4 Ton	36x20-14R	3	-----	No	3560	CR No. 3-152

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Table 12 (Continued)

Vehicle Identification	Vehicle Configuration: Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	Primary Reference Source
MEXA 8x8	48x31 - 16A	9	-----	No	19013	TR M-70-11
MEXA 10x10	42x40 - 16A	7.3	-----	No	18030	TR M-70-11
XM410E1 8x8 2-1/2 Ton	14x18	12	-----	No	16504	TR M-70-11
XM410E1 8x8 2-1/2 Ton	14x18	13	-----	No	18504	TR M-70-11
Tournadozer 4x4 Tractor	21.00x25	20	-----	No	31370	TM 3-240 18th
Bucket Loader 4x4 Tractor	14.00x24	30	-----	No	13815	TM 3-240 18th
5-Ton Forklift 4x4 Rough Terrain	16.00x24	42	-----	No	30625	TM 3-240 18th
Willys Station Wagon 4x4	7.00x15	30	-----	No	3650	TM 3-240 18th
16-Ton XM438E2 GOER 4x4 Tanker	29.5x25	15	-----	Yes	38310	TM 3-240 18th
16-Ton XM438E2 GOER 4x4 Tanker	29.5x25	15	-----	No	38310	TM 3-240 18th
M37 4x4 3/4 Ton	9.00x16	30	-----	No	7240	CR No. 3-152
M37 4x4 3/4 Ton	9.00x16	15	-----	No	7240	CR No. 3-152
M37 4x4 3/4 Ton	9.00x16	6.5	-----	No	7240	CR No. 3-152
M37 4x4 3/4 Ton	46.00 - 18x16 Terra Tires	15	-----	No	7240	CR No. 3-152
M37 4x4 3/4 Ton	46.00 - 18x16 Terra Tires	3	-----	No	7240	CR No. 3-152
M274 4x4 1/2 Ton	7.50x10	30	-----	No	1190	CR No. 3-152
M274 4x4 1/2 Ton	7.50x10	10	-----	No	1190	CR No. 3-152
M274 4x4 1/2 Ton	7.50x10	5	-----	No	1190	CR No. 3-152
M274 4x4 1/2 Ton	7.50x10	30	-----	No	1940	CR No. 3-152
M274 4x4 1/2 Ton	7.50x10	10	-----	No	1940	CR No. 3-152

(Sheet 5 of 7)

Table 12 (Continued)

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
M274 4x4 1/2 Ton	7.50x10	5	-----	No	1940	CR No. 3-152
M274 4x4 1/2 Ton	16.00 - 15x16 Terra Tires	15	-----	No	1325	CR No. 3-152
M274 4x4 1/2 Ton	16.00 - 15x16 Terra Tires	3	-----	No	1325	CR No. 3-152
M274 4x4 1/2 Ton	16.00 - 15x16 Terra Tires	15	-----	No	1940	CR No. 3-152
M274 4x4 1/2 Ton	16.00 - 15x16 Terra Tires	3	-----	No	1940	CR No. 3-152
LeTourneau Electric Digger Model L-28	75x33	75	-----	No	85000	MP No. 4-879
LeTourneau Electric Digger Model L-28	75x33	27	-----	No	85000	MP No. 4-879
LeTourneau Log Stacker Model F	75x33	40	-----	No	73220	MP No. 4-879
Timberjack 404	23.1x26 10PR Logger Special	16	-----	No	16880	B.G.S. Black Book
Mudder	46x18-16R	3	-----	No	4840	B.G.S. Black Book
Amphicat	11.5x20	1.5	-----	No	830	B.G.S. Black Book
BART 3	23.5x25	21	-----	No	74820	B.G.S. Black Book
Power Wagon	18.00-16	10	-----	No	9230	B.G.S. Black Book
Tracked Vehicle Configurations						
CAT 30/30	-----	-----	20 x 102	-----	37500	TR GL-92-13
Challenger C-65 (narrow tracks)	-----	-----	24.5 x 107	-----	33000	TR GL-92-13
Challenger C-65 (narrow tracks) w/Trailer	-----	-----	24.5 x 107	-----	39200	TR GL-92-13
Challenger C-65 (wide tracks)	-----	-----	35.5 x 107	-----	33000	TR GL-92-13
MEXA Track (articulated)	-----	-----	20 x (85+104)	-----	19680	TR M-70-11
M113 APC	-----	-----	15 x 105	-----	24200	TR M-70-11

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Table 12 (Concluded)

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Tire Size	Pressure psi	Track Size (bxl), in.	Chains (Y/N)	Test GVW, lbf	
M113 APC	-----	-----	15 x 105	-----	22600	TR M-70-11
M116	-----	-----	20 x 98	-----	8435	CR No. 3-152
M116	-----	-----	20 x 98	-----	7600	T.R. No. 3-808
M116	-----	-----	20 x 98	-----	10600	T.R. No. 3-808
Dinah 1/2 Ton	-----	-----	20 x 80	-----	4095	CR No. 3-152
Dinah 1/2 Ton	-----	-----	20 x 80	-----	4975	CR No. 3-152
M29C Weasel	-----	-----	12 x 78	-----	5960	CR No. 3-152
M29C Weasel	-----	-----	20 x 78	-----	5960	CR No. 3-152
M29C Weasel	-----	-----	20 x 78	-----	4960	CR No. 3-152
D4 Engr. Tractor (without blade)	-----	-----	13 x 62	-----	12420	CR No. 3-152
D4 Engr. Tractor (without blade)	-----	-----	24 x 62	-----	13580	CR No. 3-152
D4 Engr. Tractor (with blade)	-----	-----	13 x 62	-----	14870	CR No. 3-152
Polecat (articulated)	-----	-----	20 x (78+78)	-----	12580	CR No. 3-152
M5A4 Hi-Speed Tractor	-----	-----	17 x 117.5	-----	28350	CR No. 3-152
M56	-----	-----	20 x 93	-----	15500	CR No. 3-152
M24 Tank	-----	-----	16 x 102	-----	36800	B.G.S. Black Book
M47 Tank	-----	-----	23 x 154	-----	97200	B.G.S. Black Book

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Table 13
Wheeled Vehicle Configurations and Sources contained in the *Fine-Grained Drawbar at Nominal Slip* Database

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER01	M977 HEMTT	60375	MI 16.00R20	Rad	20/30	27.6	No	> 4	30	WES Wheels-Tracks files	BOTH
ER01	M977 HEMTT	60375	MI 16.00R20	Rad	35/40	20.6	No	> 4	32	WES Wheels-Tracks files	BOTH
ER01	LAV 25	26895	MI 11.00R16	Rad	24	30.3	No	> 4	26	WES Wheels-Tracks files	BOTH
ER01	LAV 25	26895	MI 11.00R16	Rad	42	20.6	No	> 4	28	WES Wheels-Tracks files	20%
ER01	MK48 LVS	66000	GY 16.00R21	Rad	22	28.3	No	> 4	32	WES Wheels-Tracks files	BOTH
ER01	MK48 LVS	66000	GY 16.00R21	Rad	45	19.4	No	> 4	35	WES Wheels-Tracks files	BOTH
ER01	M151	3560	7.00x16	Bias	7.5	35	No	> 4	17	B.G.S. files for CR 3-152	100%
ER01	M37	7240	9.00x16	Bias	30	13	No	> 4	26	B.G.S. files for CR 3-152	100%
ER01	M37	7240	9.00x16	Bias	6.5	35	No	> 4	20	B.G.S. files for CR 3-152	100%
ER01	M998 HMMWV	7570	Bias	Bias	20/22	14.1	No	> 4	21	WES Wheels-Tracks files	BOTH
ER01	LAV 25 (mod.)	28840	12.50R20 XL	Rad	15	38.5	No	> 4	21	WES Wheels-Tracks files	BOTH
ER01	LAV 25 (mod.)	28840	12.50R20 XL	Rad	30	24.9	No	> 4	23	WES Wheels-Tracks files	BOTH
ER02(A)	M977 HEMTT	60375	MI 16.00R20	Rad	20/30	27.6	No	> 4	30	WES Wheels-Tracks files	BOTH
ER02(A)	M977 HEMTT	60375	MI 16.00R20	Rad	35/40	20.6	No	> 4	32	WES Wheels-Tracks files	BOTH
ER02(A)	LAV 25	26895	MI 11.00R16	Rad	24	30.3	No	> 4	26	WES Wheels-Tracks files	BOTH
ER02(A)	LAV 25	26895	MI 11.00R16	Rad	42	20.6	No	> 4	28	WES Wheels-Tracks files	BOTH
ER02(A)	MK48 LVS	66000	GY 16.00R21	Rad	22	28.3	No	> 4	32	WES Wheels-Tracks files	BOTH
ER02(A)	MK48 LVS	66000	GY 16.00R21	Rad	45	19.4	No	> 4	35	WES Wheels-Tracks files	BOTH
ER02(A)	M923A1 5-Ton	32105	GY 14.00R20	Rad	18	30.6	No	> 4	23	WES R.I.P. (Willoughby)	BOTH

(Sheet 1 of 5)

Table 13 (Continued)

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER02(A)	M923A1 5-Ton	32260	MI 14.00R20	Rad	18	30.3	No	> 4	24	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923A1 5-Ton	32260	MI 14.00R20	Rad	30	22.5	No	> 4	26	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923A1 5-Ton	32105	GY 14.00R20	Rad	30	21.8	No	> 4	25	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M151	3180	7.00x16	Bias	18/22	19	No	> 4	18	T.R. M-76-5	BOTH
ER02(A)	M37	7240	9.00x16	Bias	6.5	35	No	> 4	20	B.G.S. files for CR 3-152	20%
ER02(A)	M37	7240	9.00x16	Bias	13.4	35	No	> 4	18	T.M. No. 3-240 19th Sup.	BOTH
ER02(A)	M37	7240	9.00x16	Bias	30	13	No	> 4	26	B.G.S. files for CR 3-152	20%
ER02(A)	M37	7240	9.00x16	Bias	30	13	No	> 4	26	B.G.S. files	20%
ER02(A)	M37	7240	9.00x16	Bias	39.1	15	No	> 4	22	T.M. No. 3-240 19th Sup.	BOTH
ER02(A)	M35A2	18225	9.00x20 NDCC	Bias	35/35	19	No	> 4	22	MSD files (C. May)	20%
ER02(A)	M998 HMMWV	7570	Bias	Bias	20/22	14.1	No	> 4	21	WES Wheels-Tracks files	BOTH
ER02(A)	M998 HMMWV	8420	36x12.50-16.5	Bias	20/30	15/18	No	> 4	21	T.R. GL-92-7	20%
ER02(A)	M923 5-Ton	32485	11.00x20 NDCC	Bias	25	26.6	No	> 4	26	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923 5-Ton	32485	11.00x20 NDCC	Bias	60/30	16.8	No	> 4	30	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923 5-Ton	32485	11.00x20 NDCC	Bias	60/30	16.8	No	> 4	30	MSD files (C. May)	20%
ER02(A)	M35A2 (mod)	18225	9.00R20 XL	Rad	40/22	20	No	> 4	21	MSD files (C. May)	20%
ER02(A)	M998(mod.) HMMWV	5545	37x12.50R16.5	Rad	6/8	32/24	No	> 4	14	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	5545	37x12.50R16.5	Rad	7/10	30/24	No	> 4	15	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	5545	37x12.50R16.5	Rad	10/15	25/17	No	> 4	16	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	5545	37x12.50R16.5	Rad	14/22	21/13	No	> 4	17	T.R. GL-92-7	BOTH

(Sheet 2 of 5)

Table 13 (Continued)

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER02(A)	M998(mod.) HMMWV	7570	Radial	Rad	20/22	16.7	No	> 4	20	WES Wheels-Tracks files	BOTH
ER02(A)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	6/8	33/43	No	> 4	15	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	7/10	31/38	No	> 4	16	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	10/15	26/31	No	> 4	16	T.R. GL-92-7	BOTH
ER02(A)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	14/22	22/25	No	> 4	22	T.R. GL-92-7	BOTH
ER02(A)	LAV 25 (mod.)	28840	MI 12.50R20	Rad	15	38.5	No	> 4	21	WES Wheels-Tracks files	BOTH
ER02(A)	LAV 25 (mod.)	28840	MI 12.50R20	Rad	30	24.9	No	> 4	23	WES Wheels-Tracks files	BOTH
ER02(A)	M923(mod.) 5-Ton	33585	MI 16.00R20	Rad	12	33.4	No	> 4	21	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923(mod.) 5-Ton	33790	GY 16.00R21	Rad	12	32.9	No	> 4	20	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923(mod.) 5-Ton	33585	MI 16.00R20	Rad	25	21.9	No	> 4	23	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923(mod.) 5-Ton	33790	GY 16.00R21	Rad	25	20.9	No	> 4	23	WES R.I.P. (Willoughby)	BOTH
ER02(A)	M923(mod.) 5-Ton	32500	11.00R20 XL	Rad	51/24	17.3	No	> 4	30	MSD files (C. May)	20%
ER02(A)	M35A1 (mod.)	19410	11.00x20	Bias	13	35	No	> 4	23	B.G.S. files for CR 3-152	20%
ER02(A)	M35A2 (mod.)	18225	11.00x20	Bias	20.1	25	No	> 4	24	TR M-70-11 "MEXA"	BOTH
ER02(A)	XM800W ARSV	19330	LR 70x20 4PR	Rad	14	28	No	> 4	15	M.P. M-74-6	20%
ER02(A)	DA-1500	62470	MI 24R21 XL	Rad	25	23.8	No	> 4	23	WES Wheels-Tracks files	BOTH
ER02(A)	XM410E1	16504	14.00x18	Bias	12.2	25	No	> 4	16	TR M-70-11 "MEXA"	BOTH
ER02(A)	FSU SA-8	35780	1200x500-508	Bias	28	24	No	> 4	25	T.R. GL-93-8	BOTH
ER02(A)	FSU SA-8	35780	1200x500-508	Bias	14	31.6	No	> 4	23	T.R. GL-93-8	BOTH
ER02(A)	ZIL-135	38420	1600-20	Bias	18	22.8	No	> 4	19	T.R. GL-93-10	BOTH

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Table 13 (Continued)

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER02(B)	M977 HEMTT	60375	MI 16.00R20	Rad	20/30	27.6	No	> 4	30	WES Wheels-Tracks files	BOTH
ER02(B)	M977 HEMTT	60375	MI 16.00R20	Rad	35/40	20.6	No	> 4	32	WES Wheels-Tracks files	BOTH
ER02(B)	LAV 25	26895	MI 11.00R16	Rad	24	30.3	No	> 4	26	WES Wheels-Tracks files	BOTH
ER02(B)	LAV 25	26895	MI 11.00R16	Rad	42	20.6	No	> 4	28	WES Wheels-Tracks files	BOTH
ER02(B)	MK48 LVS	66000	GY 16.00R21	Rad	22	28.3	No	> 4	32	WES Wheels-Tracks files	BOTH
ER02(B)	MK48 LVS	66000	GY 16.00R21	Rad	45	19.4	No	> 4	35	WES Wheels-Tracks files	BOTH
ER02(B)	M37	7240	9.00x16	Bias	6.5	35	No	> 4	20	B.G.S. files for CR 3-152	BOTH
ER02(B)	M37	7240	9.00x16	Bias	13.4	35	No	> 4	18	T.M. No. 3-240 19th Sup.	BOTH
ER02(B)	M37	7240	9.00x16	Bias	30	13	No	> 4	26	B.G.S. files	20%
ER02(B)	M37	7240	9.00x16	Bias	39.1	15	No	> 4	22	T.M. No. 3-240 19th Sup.	BOTH
ER02(B)	M274 Mule	1900	7.50-10	Bias	-----	~ 15	No	> 4	11	B.G.S. Files [Plot Only]	20%
ER02(B)	M998 HMMWV	7570	Bias	Bias	20/22	14.1	No	> 4	21	WES Wheels-Tracks files	BOTH
ER02(B)	M998 HMMWV	8420	36x12.50-16.5	Bias	20/30	15/18	No	> 4	21	T.R. GL-92-7	BOTH
ER02(B)	M998(mod.) HMMWV	7570	Radial	Rad	20/22	16.7	No	> 4	20	WES Wheels-Tracks files	20%
ER02(B)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	14/22	22/25	No	> 4	22	T.R. GL-92-7	BOTH
ER02(B)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	10/15	26/31	No	> 4	16	T.R. GL-92-7	BOTH
ER02(B)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	7/10	31/38	No	> 4	16	T.R. GL-92-7	BOTH
ER02(B)	M998(mod.) HMMWV	8420	37x12.50R16.5	Rad	6/8	33/43	No	> 4	15	T.R. GL-92-7	BOTH
ER02(B)	M1025(mod.) HMMWV	6305	37x12.50R16.5	Rad	14/22	22/16	No	> 4	17	T.R. GL-92-7	BOTH
ER02(B)	M1025(mod.) HMMWV	6305	37x12.50R16.5	Rad	10/15	26/20	No	> 4	16	T.R. GL-92-7	BOTH

(Sheet 4 of 5)

Table 13 (Concluded)

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER02(B)	M1025(mod.) HMMWV	6305	37x12.50R16.5	Rad	7/10	32/24	No	> 4	15	T.R. GL-92-7	BOTH
ER02(B)	M1025(mod.) HMMWV	6305	37x12.50R16.5	Rad	6/8	34/28	No	> 4	13	T.R. GL-92-7	BOTH
ER02(B)	LAV 25 (mod.)	28840	12.50R20 XL	Rad	15	38.5	No	> 4	21	WES Wheels-Tracks files	BOTH
ER02(B)	LAV 25 (mod.)	28840	12.50R20 XL	Rad	30	24.9	No	> 4	23	WES Wheels-Tracks files	BOTH
ER02(B)	M35A1 (mod.)	19410	11.00x20	Bias	13	35	No	> 4	23	B.G.S. files for CR 3-152	BOTH
ER02(B)	M35A1 (mod.)	19410	11.00x20	Bias	35.5	15	No	> 4	29	B.G.S. files for CR 3-152	20%
ER02(B)	M35A2 (mod.)	18225	11.00x20	Bias	20.1	25	No	> 4	24	TR M-70-11 "MEXA"	20%
ER02(B)	DA-1500	62470	MI 24R21 XL	Rad	25	23.8	No	> 4	23	WES Wheels-Tracks files	BOTH
ER02(B)	Timberjack 404	16880	23.1x26	Bias	16	18.4/11.0	No	> 4	15	B.G.S. Files [Plot Only]	20%
ER02(B)	Bucket Loader	13815	14x24	Bias	30	14.9	No	> 4	21	B.G.S. files at WES	100%
ER02(B)	FSU SA-8	35780	1200x500-508	Bias	28	24	No	> 4	25	T.R. GL-93-8	BOTH
ER02(B)	FSU SA-8	35780	1200x500-508	Bias	14	31.6	No	> 4	23	T.R. GL-93-8	BOTH
ER03	M37(mod.)	7240	46.00-18.00x16 TT	Bias	3	25	No	< 4	11	B.G.S. files for CR 3-152	100%
ER03	M37(mod.)	7240	46.00-18.00x16 TT	Bias	15	10	No	< 4	15	B.G.S. files for CR 3-152	100%
ER03	MEXA 10x10	18030	42x40 -16A	Bias	7.3	20	No	< 4	8	TR M-70-11 "MEXA"	BOTH
ER03	MEXA 8x8	19013	48x31 -16A	Bias	9	20	No	< 4	10	TR M-70-11 "MEXA"	BOTH
ER04	LAV 25	26895	MI 11.00R16	Rad	24	30.3	Yes	> 4	25	WES Wheels-Tracks files	BOTH
ER04	LAV 25	26895	MI 11.00R16	Rad	42	20.6	Yes	> 4	27	WES Wheels-Tracks files	BOTH

(Sheet 5 of 5)

Table 14
Tracked Vehicle Configurations and Sources contained in the *Fine-Grained Drawbar at Nominal Slip* Database

NRMM II Relation	Vehicle Identification	Test GVW lbf	Track Contact Size (bxl), in.	CPF (rel.)	NRMM II Pred. VCI-1	Data Source	20%, 100% or BOTH Databases
ER05	XM800T ARSV	19850	19x111	> 4	11	M.P. M-74-6	20%
ER05	XM800T ARSV	19850	19x111	> 4	11	B.G.S. files on M.P. M-74-6	100%
ER05	M577A1 CPC	22000	15x108	> 4	15	M.P. M-77-12	20%
ER05	M551	33460	17x143	> 4	15	M.P. M-74-6	20%
ER05	M551	33460	17x143	> 4	15	B.G.S. files on M.P. M-74-6	100%
ER05	M48 Tank	95850	28x157.5	> 4	18	B.G.S. Files -- Plot Only	20%
ER05	M48 Tank	104000	28x161.5	> 4	22	T.R. M-76-5	20%
ER05	M2 BFVS	50270	NO PADS	> 4	14	WES Wheels-Tracks files *	BOTH
ER05	M2 BFVS	50270	PADDED	> 4	14	WES Wheels-Tracks files *	BOTH
ER05	M114A1E1	15830	16.5x94	> 4	12	M.P. M-74-6	20%
ER05	M114A1E1	15830	16.5x94	> 4	12	B.G.S. files on M.P. M-74-6	100%
ER05	M113A2	24860	PADDED	> 4	16	WES Wheels-Tracks files *	BOTH
ER05	M113A1	23400	NO PADS	> 4	15	WES Wheels-Tracks files *	BOTH
ER05	M113A1	23400	PADDED	> 4	15	WES Wheels-Tracks files *	BOTH
ER05	M113A1	23410	15x105	> 4	16	T.R. M-76-5	20%
ER05	M113A1	23410	15x105	> 4	16	B.G.S. files on T.R. M-76-5	100%
ER05	M113 APC	22600	15x105	> 4	15	TR M-70-11 "MEXA"	20%
ER05	M113 APC	22600	15x105	> 4	15	B.G.S. files on T.R. M-70-11	100%
ER05	LYNX	19340	15x97	> 4	15	M.P. M-74-6	20%
ER05	LYNX	19340	15x97	> 4	15	B.G.S. files on M.P. M-74-6	100%

(Continued)

Table 14 (Concluded)

NRMM II Relation	Vehicle Identification	Test GVW lbf	Track Contact Size (bxl), in.	CPF (rel.)	NRMM II Pred. VCI-1	Data Source	20%, 100% or BOTH Databases
ER06	M2 BFVS	50270	NO PADS	> 4	14	WES Wheels-Tracks files *	BOTH
ER06	M2 BFVS	50270	PADDED	> 4	14	WES Wheels-Tracks files *	BOTH
ER06	M113A2	24860	PADDED	> 4	16	WES Wheels-Tracks files *	BOTH
ER06	M113A1	23400	NO PADS	> 4	15	WES Wheels-Tracks files *	BOTH
ER06	M113A1	23400	PADDED	> 4	15	WES Wheels-Tracks files *	BOTH
ER06	M113 APC	22600	15x105	> 4	15	TR M-70-11 "MEXA"	20%
ER06	M113 APC	22600	15x105	> 4	15	B.G.S. files on T.R. M-70-11	100%
ER07(A)	Polecat Model 941	12580	20x156	< 4	6	B.G.S. files for CR 3-152	20%
ER07(A)	MEXA Track	19680	20x(85+104)	< 4	7	TR M-70-11 "MEXA"	20%
ER07(A)	MEXA Track	19680	20x(85+104)	< 4	7	B.G.S. files on T.R. M-70-11	100%
ER07(A)	M29C Weasel	4960	20x78	< 4	5	TR No. 3-641	20%
ER07(A)	M29C Weasel	4960	20x78	< 4	5	B.G.S. files for CR 3-152	BOTH
ER07(A)	M29C Weasel	5960	12x78	< 4	11	B.G.S. files for CR 3-152	BOTH
ER07(A)	M29C Weasel	5960	20x78	< 4	6	B.G.S. files for CR 3-152	BOTH
ER07(A)	M116	8435 & 10610	20x98	< 4	8	B.G.S. files for CR 3-152	20%
ER07(B)	D9H	92900	30x133	> 4	17	M.P. M-78-5	BOTH
ER07(B)	D8H	67800	24x115	> 4	18	M.P. M-78-5	BOTH
ER07(B)	D4 w/o Blade	13580	24x62	> 4	9	B.G.S. files for CR 3-152	100%

Table 15
Wheeled Vehicle Configurations & Sources associated with data "Rejected" from the *Fine-Grained Drawbar at Nominal Slip* Database

NRMM II Relation	Vehicle Identification	Test GVW lbf	Tire Size	Tire Type	Tire Press psi	Tire δ/h %	Tire Chains (Y/N)	CPF (rel.)	NRMM II Pred. VCI-1	Source	20%, 100% or BOTH Databases
ER01	BAC MTB (HML)	65000	20.5R25	Rad	47/58	18	No	> 4	50	T.R. GL-89-2	20
ER02(A)	BAC MTB (HML)	65000	20.5R25	Rad	25/40	25	No	> 4	50	T.R. GL-89-2	20
ER02(A)	BAC MTB (HML)	65000	20.5R25	Rad	47/58	18	No	> 4	50	T.R. GL-89-2	20
ER02(B)	BAC-MTB-I (HML)	172160	22/65R25	Rad	30, 50	17.5	No	> 4	80	T.R. GL-88-8 & "Vol. II" in prep.	20
ER02(B)	M35A1 (mod.)	19410	11.00x20	Bias	35.5	15	No	> 4	29	B.G.S. files for CR 3-152	20
ER02(B)	Taylor Log Skidder	16495	23.1x26	Bias	16	20.2/12.7	No	> 4	14	M.P. M-69-1	BOTH
ER02(B)	Taylor Log Skidder	20870	23.1x26	Bias	16	18.8/29.1	No	> 4	16	M.P. M-69-1	BOTH
ER03	Major/Minor	3550	16.00x14.5 - 6	Bias	10	-----	No	< 4	5	MP M-68-4	BOTH
ER04	Meili Flex-Trac 4x4	9100	10-20	Bias	-----	Est. 15	Yes	> 4	24	M.P. No. 4-412	100
ER04	Meili Flex-Trac 6x6	9100	10-20	Bias	-----	Est. 15	Yes	> 4	19	M.P. No. 4-412	100

Table 16
Tracked Vehicle Configurations & Sources associated with data "REJECTED" from the *Fine-Grained Drawbar at Nominal Slip* Database

NRMM II Relation	Vehicle Identification	Test GVW lbf	Track Contact Size (bxl), in.	CPF (rel.)	NRMM II Pred. VCI-1	Data Source	20%, 100% or BOTH Databases
ER05	CAT 30/30	37500	20x102	> 4	16	T.R. GL-92-13	BOTH
ER05	D8H	67800	24x115	> 4	12	M.P. M-78-5	BOTH
ER05	D9H	92900	30x133	> 4	13	M.P. M-78-5	BOTH
ER05	LVTP-7	46953	21x153	> 4	15	T.R. GL-84-12	100
ER06	D4 w/o Blade	13580	24x62	> 4	15	B.G.S. files for CR 3-152	100
ER06	D8H	67800	24x115	> 4	12	M.P. M-78-5	BOTH
ER06	MMC-MTB-I (HML)	184000	24x135, 20x55(2)	> 4	70	T.R. GL-88-8 & "Vol. II" files	BOTH
ER07	M116	10600	20x98	< 4	7	TR No. 3-808	BOTH
ER07	M29C Weasel	5960	20x78	< 4	7	B.G.S. files	20
ER07	M973 SUSV	13790	RUBBER	< 4	5	WES Wheels-Tracks files	BOTH

Table 17
Wheeled Vehicle Configurations and Sources contained in the *Fine-Grained SLIP at "Maximum" Soil Strength* Database

Vehicle Configuration						Primary Reference Source	NRMM II Relation
Vehicle Identification	Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)		
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER08
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER08
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER08
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER08
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER08
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER08
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER08
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER08
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER08
DA-1500 Crash Fire Rescue (CFR) 8x8 Articulated	Michelin 24R21 XL	25	No	62470	>4 psi	MSD Wh vs Tk files	ER09
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER09
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER09
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER09
M998 HMMWV 4x4	MI 12.5R16.5 XL (Front) GY 12.5R16.5 LT (Rear)	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER09
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER09
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER09
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER09

(Sheet 1 of 6)

Table 17 (Continued)

Vehicle Configuration						Primary Reference Source	NRMM II Relation
Vehicle Identification	Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)		
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER09
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER09
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER09
MK48 8x8 Articulated LVS (Logistics Veh. System)	Michelin 16.00R20 XL	45	No	66000	>4 psi	MSD Wh vs Tk files	ER09
DA-1500 Crash Fire Rescue (CFR) 8x8 Articulated	Michelin 24R21 XL	25	No	62470	>4 psi	MSD Wh vs Tk files	ER10
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER10
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER10
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER10
M998 HMMWV 4x4	MI 12.5R16.5 XL (Front) GY 12.5R16.5 LT (Rear)	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER10
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER10
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER10
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER10
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER10
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER10
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER10
MK48 8x8 Articulated LVS (Logistics Veh. System)	Michelin 16.00R20 XL	45	No	66000	>4 psi	MSD Wh vs Tk files	ER10
MEXA 10X10	42.00X40.00-16A	7.3	No	18030	< 4 psi	T.R. M-70-11	ER11
MEXA 8X8	48.00X31.00-16A	9	No	19013	< 4 psi	T.R. M-70-11	ER11

Table 17 (Continued)

Vehicle Configuration						Primary Reference Source	NRMM II Relation
Vehicle Identification	Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)		
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER12
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER12
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER12
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER12
DA-1500 Crash Fire Rescue (CFR) 8x8 Articulated	Michelin 24R21 XL	25	No	62470	>4 psi	MSD Wh vs Tk files	ER16
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER16
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER16
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER16
M998 HMMWV 4x4	MI 12.5R16.5 XL (Front) GY 12.5R16.5 LT (Rear)	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER16
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER16
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER16
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER16
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER16
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER16
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER16
MK48 8x8 Articulated LVS (Logistics Veh. System)	Michelin 16.00R20 XL	45	No	66000	>4 psi	MSD Wh vs Tk files	ER16

Table 17 (Continued)

Vehicle Configuration						Primary Reference Source	NRMM II Relation
Vehicle Identification	Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)		
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER17
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER17
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER17
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER17
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER17
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER17
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER17
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER17
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER17
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER18
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER18
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER18
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER18
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER18
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER18
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER18
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER18
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER18

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Table 17 (Continued)

Vehicle Configuration						Primary Reference Source	NRMM II Relation
Vehicle Identification	Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)		
DA-1500 Crash Fire Rescue (CFR) 8x8 Articulated	Michelin 24R21 XL	25	No	62470	>4 psi	MSD Wh vs Tk files	ER19
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	20/30	No	60375	>4 psi	MSD Wh vs Tk files	ER19
M977 HEMTT 10-Ton 8x8	Michelin 16.00R20 XL	35/40	No	60375	>4 psi	MSD Wh vs Tk files	ER19
M998 HMMWV 4x4	Goodyear Wrangler Bias 36x12.50-16.5	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER19
M998 HMMWV 4x4	MI 12.5R16.5 XL (Front) GY 12.5R16.5 LT (Rear)	20 / 22	No	7570	>4 psi	MSD Wh vs Tk files	ER19
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	42	No	26895	>4 psi	MSD Wh vs Tk files	ER19
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16	24	No	26895	>4 psi	MSD Wh vs Tk files	ER19
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	30	No	28840	>4 psi	MSD Wh vs Tk files	ER19
LAV25 Light Armored Vehicle 8x8	Michelin 12.50R20 XL	15	No	28840	>4 psi	MSD Wh vs Tk files	ER19
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	22	No	66000	>4 psi	MSD Wh vs Tk files	ER19
MK48 8x8 Articulated LVS (Logistics Veh. System)	Goodyear 16.00R21	45	No	66000	>4 psi	MSD Wh vs Tk files	ER19
MK48 8x8 Articulated LVS (Logistics Veh. System)	Michelin 16.00R20 XL	45	No	66000	>4 psi	MSD Wh vs Tk files	ER19
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER20
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER20
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER20
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER20

Table 17 (Concluded)

Vehicle Identification	Vehicle Configuration: Tire Size	Tire Press., psi	Chains (Y/N)	Test GVW, lbf	CPF (relative)	Primary Reference Source	NRMM II Relation
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER21
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER21
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER21
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	24	Yes	26895	>4 psi	MSD Wh vs Tk files	ER21
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Snow Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER22
LAV25 Light Armored Vehicle 8x8	Michelin 11.00R16 w/ Plastic Cleated Chains	42	Yes	26895	>4 psi	MSD Wh vs Tk files	ER22

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Table 18
Tracked Vehicle Configurations and Sources contained in the *Fine-Grained SLIP at "Maximum" Soil Strength* Database

Vehicle Configuration					Data Source	NRMM II Relation
Vehicle Identification	Track Size (bxl), in.	Pads (Y/N)	Test GVW, lbf	CPF (relative)		
M113A1 Armored Personnel Carrier	15 x 109	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER13
M113A1 Armored Personnel Carrier	15 x 109	No	23400	> 4 psi	MSD Wh vs Tk files	ER13
M113A2 Armored Personnel Carrier	15 x 109	Yes	24860	> 4 psi	MSD Wh vs Tk files	ER13
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER13
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	No	50270	> 4 psi	MSD Wh vs Tk files	ER13
M113A1 Armored Personnel Carrier	15 x 109 (New)	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER14
M113A1 Armored Personnel Carrier	15 x 109	No	23400	> 4 psi	MSD Wh vs Tk files	ER14
M113A1 Armored Personnel Carrier	15 x 109	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER14
M113A2 Armored Personnel Carrier	15 x 109	Yes	24860	> 4 psi	MSD Wh vs Tk files	ER14
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER14
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	No	50270	> 4 psi	MSD Wh vs Tk files	ER14
MEXA TRACKED	20x(85+104)	No	19680	< 4 psi	T.R. M-70-11	ER15
M113A1 Armored Personnel Carrier	15 x 109 (New)	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER23
M113A2 Armored Personnel Carrier	15 x 109	Yes	24860	> 4 psi	MSD Wh vs Tk files	ER23
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER23
M113A1 Armored Personnel Carrier	15 x 109	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER24
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER24

(Continued)

Table 18 (Concluded)

Vehicle Configuration					Data Source	NRMM II Relation
Vehicle Identification	Track Size (bxl), in.	Pads (Y/N)	Test GVW, lbf	CPF (relative)		
M113A1 Armored Personnel Carrier	15 x 109	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER25
M113A2 Armored Personnel Carrier	15 x 109	Yes	24860	> 4 psi	MSD Wh vs Tk files	ER25
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER25
M113A1 Armored Personnel Carrier	15 x 109	Yes	23400	> 4 psi	MSD Wh vs Tk files	ER26
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	Yes	50270	> 4 psi	MSD Wh vs Tk files	ER26
M113A1 Armored Personnel Carrier	15 x 109	No	23400	> 4 psi	MSD Wh vs Tk files	ER27
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	No	50270	> 4 psi	MSD Wh vs Tk files	ER27
M113A1 Armored Personnel Carrier	15 x 109	No	23400	> 4 psi	MSD Wh vs Tk files	ER28
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	No	50270	> 4 psi	MSD Wh vs Tk files	ER28
M113A1 Armored Personnel Carrier	15 x 109	No	23400	> 4 psi	MSD Wh vs Tk files	ER29
M2 Bradley Fighting Vehicle System (BFVS)	21 x 157	No	50270	> 4 psi	MSD Wh vs Tk files	ER29
M973 SUSV (Small Unit Support Veh.), Articulated	24 x 78(2) Rubber Track	-----	13790	< 4 psi	MSD Wh vs Tk files	ER30
M973 SUSV (Small Unit Support Veh.), Articulated	24 x 78(2) Rubber Track	-----	13790	< 4 psi	MSD Wh vs Tk files	ER31

Table 19
Wheeled Vehicle Configurations and Sources contained in the *Fine-Grained Motion Resistance* Database

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR01	M998 HMMWV	12.5R16.5	R	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains & cleats	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains & cleats	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR01	M977 (HEMTT), 8X8	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR01	M977 (HEMTT), 8X8	16.0R20	R	27.6	60375	>4 psi	WES Wheels-Tracks Files
MR01	M977 (HEMTT), 8X8, w/chains	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR02	M985 10 ton 8X8	16R20XL	R	19.3	62250	>4 psi	T.R. GL-85-4
MR02	M977 10 ton 8X8	16R20XL	R	19.7	60145	>4 psi	T.R. GL-85-4
MR02	XM800W 6X6, ARSV	LR70X20-4	R	28.0	19330	>4 psi	M.P. M-74-6

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Table 19 (Continued)

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR02	Techo Demo 5 ton	14R20XL	R	23.1	32210	>4 psi	T.R. GL-89-9
MR02	M923 5 ton	14R20XL	R	23.1	32190	>4 psi	T.R. GL-89-9
MR02	M998 HMMWV	12.5R16.5	R	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8, w/chains	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8, w/chains & cleats	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR02	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR02	M977 (HEMTT), 8X8	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR02	M977 (HEMTT), 8X8	16.0R20	R	27.6	60375	>4 psi	WES Wheels-Tracks Files
MR02	MK48 (LVS), 8X8	16.0R21	R	19.4	66000	>4 psi	WES Wheels-Tracks Files
MR02	MK48 (LVS), 8X8	16.0R21	R	28.3	66000	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8 w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files

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Table 19 (Continued)

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR03	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR03	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR04	Taylor Log Skidder (MS-112)	23.1X26	B	16.0	16495	>4 psi	M.P. M-69-1
MR04	Taylor Log Skidder (MS-112)	23.1X26	B	20.0	20870	>4 psi	M.P. M-69-1
MR04	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR05	XM410E1 10 ton 8X8	14X18	B	25.0	16504	>4 psi	T.R. M-70-11
MR05	M35A2 2-1/2 ton 6X6	11X20	B	25.0	18225	>4 psi	T.R. M-70-11
MR05	Tatra 813 10 ton, 8X8, Cargo Truck	15-21TO	B	29.0	50250	>4 psi	T.R. GL-90-3
MR05	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR06	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR07	Mexa 2-1/2 ton 10X10	42X40-16A	B	20.0	18030	<4 psi	T.R. M-70-11
MR07	Mexa 2-1/2 ton 8X8	48X31-16A	B	20.0	19013	<4 psi	T.R. M-70-11
MR12	M998 HMMWV	12.5R16.5	R	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8, w/chains	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8, w/chains & cleats	11.0R20	R	20.6	26895	>4 psi	WES Wheels-Tracks Files

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Table 19 (Continued)

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR12	LAV25, 8X8, w/chains & cleats	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8, w/chains	11.0R20	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR12	M977 (HEMTT), 8X8	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR12	M977 (HEMTT), 8X8	16.0R20	R	27.6	60375	>4 psi	WES Wheels-Tracks Files
MR12	M977 (HEMTT), 8X8, w/chains	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR13	M985 10 ton 8X8	16R20XL	R	19.3	62250	>4 psi	T.R. GL-85-4
MR13	M977 10 ton 8X8	16R20XL	R	19.7	60145	>4 psi	T.R. GL-85-4
MR13	XM800W 6X6, ARSV	LR70X20-4	R	28.0	19330	>4 psi	M.P. M-74-6
MR13	Techo Demo 5 ton	14R20XL	R	23.1	32210	>4 psi	T.R. GL-89-9
MR13	M923 5 ton	14R20XL	R	23.1	32190	>4 psi	T.R. GL-89-9
MR13	M998 HMMWV	12.5R16.5	R	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files

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Table 19 (Continued)

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR13	LAV25, 8X8, w/chains	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8, w/chains & cleats	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR13	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR13	M977 (HEMTT), 8X8	16.0R20	R	20.5	60375	>4 psi	WES Wheels-Tracks Files
MR13	M977 (HEMTT), 8X8	16.0R20	R	27.6	60375	>4 psi	WES Wheels-Tracks Files
MR13	MK48 (LVS), 8X8	16.0R21	R	19.4	66000	>4 psi	WES Wheels-Tracks Files
MR13	MK48 (LVS), 8X8	16.0R21	R	28.3	66000	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8	11.0R16	R	30.3	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8, w/chains	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8 w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8	12.5R20	R	34.6	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8, w/chains & cleats	11.0R16	R	20.6	26895	>4 psi	WES Wheels-Tracks Files
MR14	LAV25, 8X8	12.5R20	R	27.1	26895	>4 psi	WES Wheels-Tracks Files
MR15	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR16	Tatra 813 10 ton, 8X8, Cargo Truck	15-21TO	B	29.0	50250	>4 psi	T.R. GL-90-3

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Table 19 (Concluded)

NRMM II Relation	Vehicle Configuration						Data Source
	Vehicle Identification	Tire Size	Bias/ Radial	Average δ/h, %	Test GVW, lbf	CPF (relative)	
MR16	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR17	M998 HMMWV	12.5LT16.5	B	14.1	7570	>4 psi	WES Wheels-Tracks Files
MR18	None						

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Table 20
Tracked Vehicle Configurations and Sources contained in the *Fine-Grained Motion Resistance* Database

NRMM II Relation	Vehicle	Test GVW, lbf	CPF (relative)	Data Source
MR10	M113 (APC)	22600	>4 psi	T.R. M-70-11
MR10	Mexa Tracked	19680	<4 psi	T.R. M-70-11
MR10	XM800T ARSV	19850	>4 psi	M.P. M-74-6
MR10	Lynx , ARSV	19340	>4 psi	M.P. M-74-6
MR10	M114A1E1	15830	>4 psi	M.P. M-74-6
MR10	M551	33460	>4 psi	M.P. M-74-6
MR10	M113A1 APC	23400	> 4 psi	WES Wheels-Tracks Files
MR10	M113A2 APC	24860	> 4 psi	WES Wheels-Tracks Files
MR10	M2 BFVS	50270	> 4 psi	WES Wheels-Tracks Files
MR11	M113A1 APC	23400	> 4 psi	WES Wheels-Tracks Files
MR11	M2 BFVS	50270	> 4 psi	WES Wheels-Tracks Files
MR19	XM800T ARSV	19850	>4 psi	M.P. M-74-6
MR19	Lynx , ARSV	19340	>4 psi	M.P. M-74-6
MR19	M114A1E1	15830	>4 psi	M.P. M-74-6
MR19	M551	33460	>4 psi	M.P. M-74-6
MR19	M116 Ampn. Cargo	10600	<4 psi	T.R. No. 3-808 (1-68)
MR19	M116 Ampn. Cargo	7600	<4 psi	T.R. No. 3-808 (1-68)
MR19	M113A1 APC	23400	> 4 psi	WES Wheels-Tracks Files
MR19	M113A2 APC	24860	> 4 psi	WES Wheels-Tracks Files
MR19	M2 BFVS	50270	> 4 psi	WES Wheels-Tracks Files
MR20	M113A1 APC	23400	> 4 psi	WES Wheels-Tracks Files
MR20	M2 BFVS	50270	> 4 psi	WES Wheels-Tracks Files

Table 21
Vehicle Configurations and Sources contained in the *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* Database

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Track Width, in.	Track Length on Ground, in.	Flexible/ Girderized	Test GVW, lbf	No. of Assemblies	
M60 Tank	28	171	Flexible	93620	1	B.G.S. files on T.R. M-76-5
M113A1 APC	15	105	Flexible	23410	1	B.G.S. files on T.R. M-76-5
M29C Weasel	20	78	Flexible	5970	1	T.M. No. 3-240 15th Sup.
M29C Weasel	20	78	Flexible	6970	1	T.M. No. 3-240 15th Sup.
M29C Weasel	20	78	Flexible	5560	1	T.M. No. 3-240 17th Sup.
M5A4 Hi-Speed Tractor	17	117	Flexible	25230	1	T.M. No. 3-240 17th Sup.
Stnd D7 Engineer Tractor	20	95	Girderized	27000	1	T.M. No. 3-240 17th Sup.
Stnd D4 Engineer Tractor	13	61	Girderized	14870	1	T.M. No. 3-240 17th Sup.
Stnd D6 Engineer Tractor	16	86	Girderized	22667	1	T.M. No. 3-240 17th Sup.

Table 22
Vehicle Configurations and Sources contained in the *Tracked Vehicle SLIP at "Maximum" Soil Strength on Coarse-Grained Soils* Database

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Track Width, in.	Track Length on Ground, in.	Flexible/ Girderized	Test GVW, lbf	No. of Assemblies	
M60 Tank	28	171	Flexible	93620	1	B.G.S. files on T.R. M-76-5
M113A1 APC	15	105	Flexible	23410	1	B.G.S. files on T.R. M-76-5
M29C Weasel	20	78	Flexible	5970	1	T.M. No. 3-240 15th Sup.
M29C Weasel	20	78	Flexible	6970	1	T.M. No. 3-240 15th Sup.
M5A4 Hi-Speed Tractor	17	117	Flexible	25230	1	T.M. No. 3-240 17th Sup.
Stnd D7 Engineer Tractor	20	95	Girderized	27000	1	T.M. No. 3-240 17th Sup.
HD21 Bulldozer	Not Available	Not Available	Girderized	65000	Not Available	B.G.S. files on MEACE

Table 23
Vehicle Configurations and Sources contained in the *Tracked Vehicle Motion Resistance on Coarse-Grained Soils* Database

Vehicle Configuration						Primary Reference Source
Vehicle Identification	Track Width, in.	Track Length on Ground, in.	Flexible/ Girderized	Test GVW, lbf	No. of Assemblies	
M60 Tank	28	171	Flexible	93620	1	B.G.S. files on T.R. M-76-5
M113A1 APC	15	105	Flexible	23410	1	B.G.S. files on T.R. M-76-5
M29C Weasel	20	78	Flexible	5560	1	T.M. No. 3-240 17th Sup.
M5A4 Hi-Speed Tractor	17	117	Flexible	25230	1	T.M. No. 3-240 17th Sup.
M4 Hi-Speed Tractor	17	131	Flexible	28700	1	T.M. No. 3-240 17th Sup.
M4 Hi-Speed Tractor	17	131	Flexible	30250	1	T.M. No. 3-240 17th Sup.
Stnd D4 Engineer Tractor	13	61	Girderized	14870	1	T.M. No. 3-240 17th Sup.
Stnd D6 Engineer Tractor	16	86	Girderized	22667	1	T.M. No. 3-240 17th Sup.
Stnd D7 Engineer Tractor	20	95	Girderized	27000	1	T.M. No. 3-240 17th Sup.
HD21 Bulldozer	Not Available	Not Available	Girderized	65000	Not Available	B.G.S. files on MEACE

Table 24
Vehicles and Test Locations contained in the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* Database

Vehicle Identification	Tire b in.	Tire d in.	Wheel Load lbf	Test Location
M151, 1/4-TON; 6-PR TIRES	7.5	27.7	860	WES Laboratory
M151, 1/4-TON; 4-PR TIRES	16.1	24.3	890	WES Laboratory
M37, 3/4 TON, 8 PR TIRES	10.2	32.8	1810	WES Laboratory
M38A1, 4X4 (JEEP)	7.15	30.8	642	PADRE ISLAND, TEX
M38A1, 4X4 (JEEP)	7.15	30.8	740	PADRE ISLAND, TEX
M38A1, 4X4 (JEEP)	7.15	30.8	800	PADRE ISLAND, TEX
M37, 4X4 TRUCK, 3/4 TON	10	35.2	1422	PADRE ISLAND, TEX
M37, 4X4 TRUCK, 3/4 TON	10	35.2	1602	PADRE ISLAND, TEX
M37, 4X4 TRUCK, 3/4 TON	10	35.2	1797	PADRE ISLAND, TEX
M37, 4X4 TRUCK, 3/4 TON	10	35.2	1422	CAPE COD, MASS.
M135, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	2908	PADRE ISLAND, TEX
M135, 6X6 TRUCK, 2-1/2TON	11.5	43.6	3125	MS River Bridge, Vicksburg
M34, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	1962	SUSCINIO, FRANCE
M34, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	2796	LA TURBALLE,FRANCE
DUKW 353, 6X6 TRUCK, 2-1/2-TON	11.47	40.6	2445	LA TURBALLE, FRANCE
DUKW 353, 6X6 TRUCK, 2-1/2-TON	11.47	40.6	3278	LA TURBALLE, FRANCE
DUKW 353, 6X6 TRUCK, 2-1/2-TON	11.47	40.6	3278	SUSCINIO, FRANCE
DUKW 353, 6X6 TRUCK, 2-1/2 TON	11.47	40.6	2548	CAPE COD, MASS.
M41, 6X6 TRUCK, 5-TON	15.1	48.9	3845	PADRE ISLAND, TEX
BUCKET LOADER, 4X4 TRACTOR	14.25	53.3	2266	MS River Bridge, Vicksburg
TOURNADOZER, 4X4 TRACTOR	22.6	69.4	7768	MS River Bridge, Vicksburg
GOER, 4X4 CARGO CARRIER, 5-TON (18-26)	29.6	74	6668	MS River Bridge, Vicksburg
GOER, 4X4 CARGO CARRIER, 5-TON (15-34)	29.6	74	6668	MS River Bridge, Vicksburg

Table 25
Vehicle Configurations and Sources contained in the *Wheeled Vehicle SLIP at "Maximum" Soil Strength on Coarse-Grained Soils* Database

Vehicle Configuration											
Vehicle Identification	Tire Size	Tire Pressure psi	Bias/ Radial	Section Width in.	Section Height in.	Tire Diameter in.	Tire Defl. in.	Total No. of Tires	Test GVW lbf	Tire "Stiffness" [X_{TS}]	Primary Reference Source
M35A2 (modified)	11.00-20 12PR (Singles)	35	Bias	11	9.5	42	1.55	6	18225	0.0158	B.G.S. files on T.R. M-76-5
M998 HMMWV	36x12.50-16.5 LT	20F 30R	Bias	12	9	35.2	1.49	4	8420	0.0161	T.R. GL-92-7
M998 (mod.) HMMWV	37x12.50R16.5 MT	14F 22R	Radials	11.6	9.5	36.7	1.45	4	8420	0.0076	T.R. GL-92-7
M998 (mod.) HMMWV	37x12.50R16.5 MT	10F 15R	Radials	11.6	9.5	36.7	2.66	4	8420	0.0140	T.R. GL-92-7
M998 (mod.) HMMWV	37x12.50R16.5 MT	7F 10R	Radials	11.6	9.5	36.7	3.23	4	8420	0.0170	T.R. GL-92-7
M998 (mod.) HMMWV	37x12.50R16.5 MT	6F 8R	Radials	11.6	9.5	36.7	3.61	4	8420	0.0190	T.R. GL-92-7
M1025 (mod.) HMMWV	37x12.50R16.5 MT	14F 22R	Radials	11.6	9.5	36.7	1.5	4	6305	0.0079	T.R. GL-92-7
M1025 (mod.) HMMWV	37x12.50R16.5 MT	10F 15R	Radials	11.6	9.5	36.7	1.9	4	6305	0.0100	T.R. GL-92-7
M1025 (mod.) HMMWV	37x12.50R16.5 MT	7F 10R	Radials	11.6	9.5	36.7	2.4	4	6305	0.0126	T.R. GL-92-7
M1025 (mod.) HMMWV	37x12.50R16.5 MT	6F 8R	Radials	11.6	9.5	36.7	2.75	4	6305	0.0145	T.R. GL-92-7

Table 26
Vehicles and Test Locations contained in the *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* Database

Vehicle Identification	Tire b in.	Tire d in.	Wheel Load lbf	Test Location
M37, 4X4 TRUCK, 3/4-TON	10	35.2	1797	PADRE ISLAND, TEX.
M135, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	2458	PADRE ISLAND, TEX
M135, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	2908	PADRE ISLAND, TEX
M135, 6X6 TRUCK, 2-1/2-TON	11.5	43.6	3053	MS River Bridge, Vicksburg
M135(mod.), 4X4 w/ 11.00-20 NDCC 12PR	11.5	43.6	4402	MS River Bridge, Vicksburg
DUKW 353, 6X6 TRUCK, 2-1/2-TON	11.47	40.6	2548	CAPE COD, MASS.
M41, 6X6 TRUCK, 2-1/2-TON	15.1	48.9	3845	PADRE ISLAND, TEX.
M41, 6X6 TRUCK, 2-1/2-TON	15.1	48.9	4695	PADRE ISLAND, TEX.
BUCKET LOADER, 4X4 TRACTOR	14.25	53.3	3399	MS River Bridge, Vicksburg
TOURNADOZER, 4X4 TRACTOR	22.6	69.4	7768	MS River Bridge, Vicksburg
GOER, 4X4 CARGO CARRIER, 5-TON (18-26)	29.6	74	6668	MS River Bridge, Vicksburg
GOER, 4X4 CARGO CARRIER, 5-TON (15-34)	29.6	74	6668	MS River Bridge, Vicksburg

Table 27
Wheeled Vehicle Configurations and Sources contained in the *Muskeg One-Pass Vehicle Cone Index* Database

Vehicle Identification	GVW lbf	Section Width [a] in.	Outside Diameter [a] in.	No. of Tires	Primary Reference Source
M38A1	3465	7.15	30.8	4	WES Muskeg files (B.G.S.)
Volvo	4630	10.2	35.8	4	WES Muskeg files (B.G.S.)
Landrover	5000	8.5	24.4	4	WES Muskeg files (B.G.S.)
Tree Farmer	14000	23.8	62.1	4	WES Muskeg files (B.G.S.)
Iron Mule	12500	12.4	56.3	4	WES Muskeg files (B.G.S.)
Timberjack	16000	18.4	65.8	4	WES Muskeg files (B.G.S.)

[a] Undeflected and Highway Inflation Pressure.

Table 28
Tracked Vehicle Configurations and Sources contained in the *Muskeg One-Pass Vehicle Cone Index* Database

Vehicle Identification	GVW lbf	Track Width in.	Track Length on ground in.	Primary Reference Source
RAT	1975	21	41 (2) [a]	T.R. No. 3-656 Report 2
Bombardier	2160	26	62	T.R. No. 3-656 Report 2
RAT	2775	21	41 (2) [a]	T.R. No. 3-656 Report 2
Bombardier	2960	26	62	T.R. No. 3-656 Report 2
M29C Weasel	4919	20	78	T.R. No. 3-656 Reports 1 & 2
M29C Weasel	5919	20	78	T.R. No. 3-656 Report 2
M29C Weasel	5810	12	78	T.R. No. 3-656 Report 2
Nodwell RN21B	7900	28	85	T.R. No. 3-656 Report 2
M116 ACC	7600	20	98	T.R. No. 3-744
Nodwell RN110D	10580	40	135	T.R. No. 3-656 Report 2
M76 Otter	12200	30	97	T.R. No. 3-656 Report 2
M56 Gun	12950	20	86	T.R. No. 3-656 Report 2
Nodwell RN110D	19380	40	135	T.R. No. 3-656 Report 2
Buffalo	32900	48	108	T.R. No. 3-656 Reports 1 & 2
M59 APC	40200	21	121	T.R. No. 3-744
M41 Tank	45500	21	128	T.R. No. 3-744
M60A1 Tank	95000	28	167	T.R. No. 3-744
Dinah	5000	20	40 (2) [a]	T.R. No. 3-656 Reports 1 & 2
XM571 Dynatrack	7400	18	52 (2) [a]	MSD files (B.G.S.)
Nodwell RN10	3500	24	63	MSD files (B.G.S.)
Land Rover Tracked	7500	12	33 (2) [a]	MSD files (B.G.S.)
M113 APC	18200	15	105	MSD files (B.G.S.)
RAT	2475	21	41 (2) [a]	T.R. No. 3-656 Report 2
BV202	8600	26	150	MSD files (B.G.S.)
Go Track	27600	20	114	MSD files (B.G.S.)

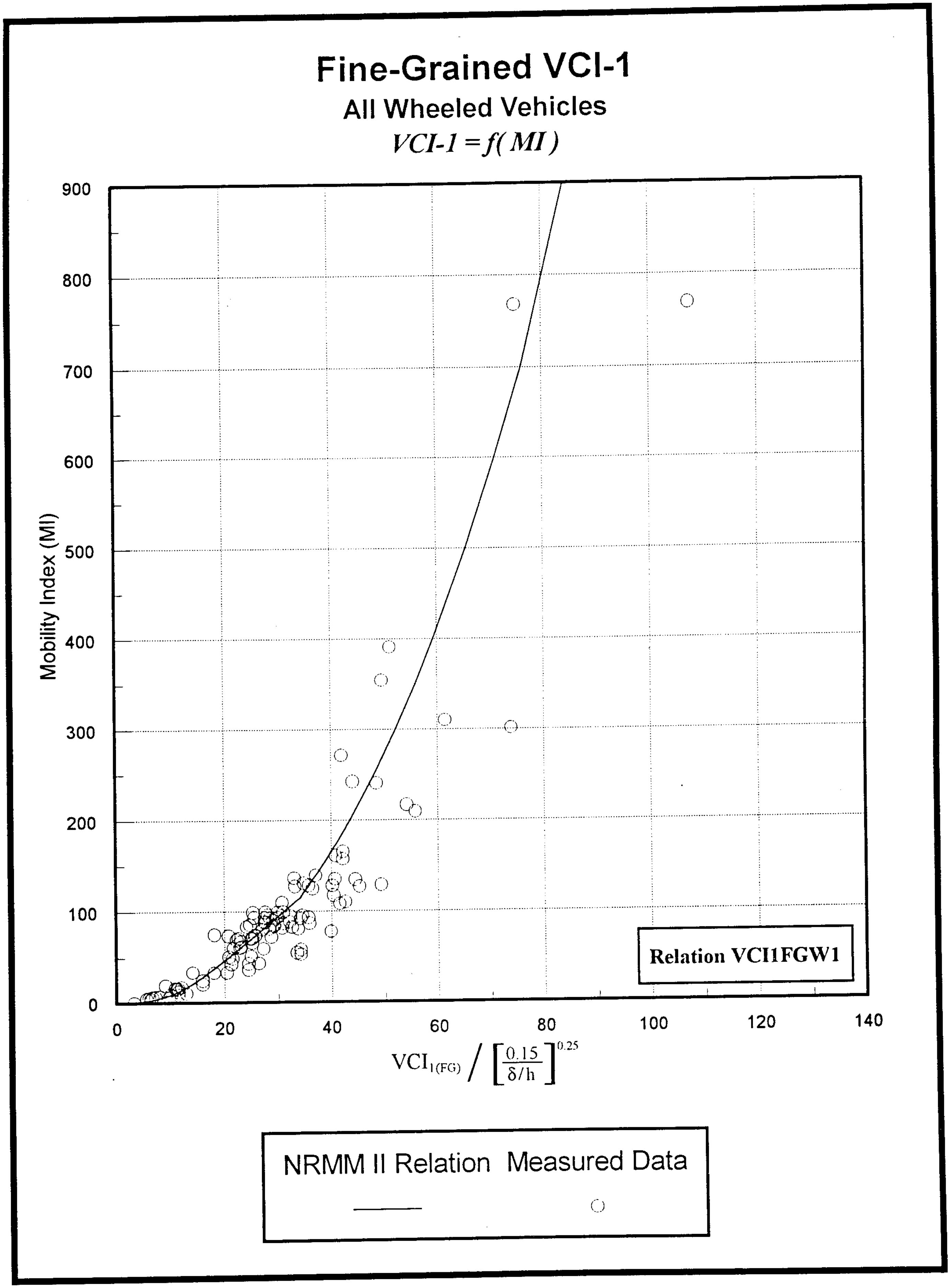
[a] The number in parenthesis means that the vehicle had more than one assembly each having the track length shown.

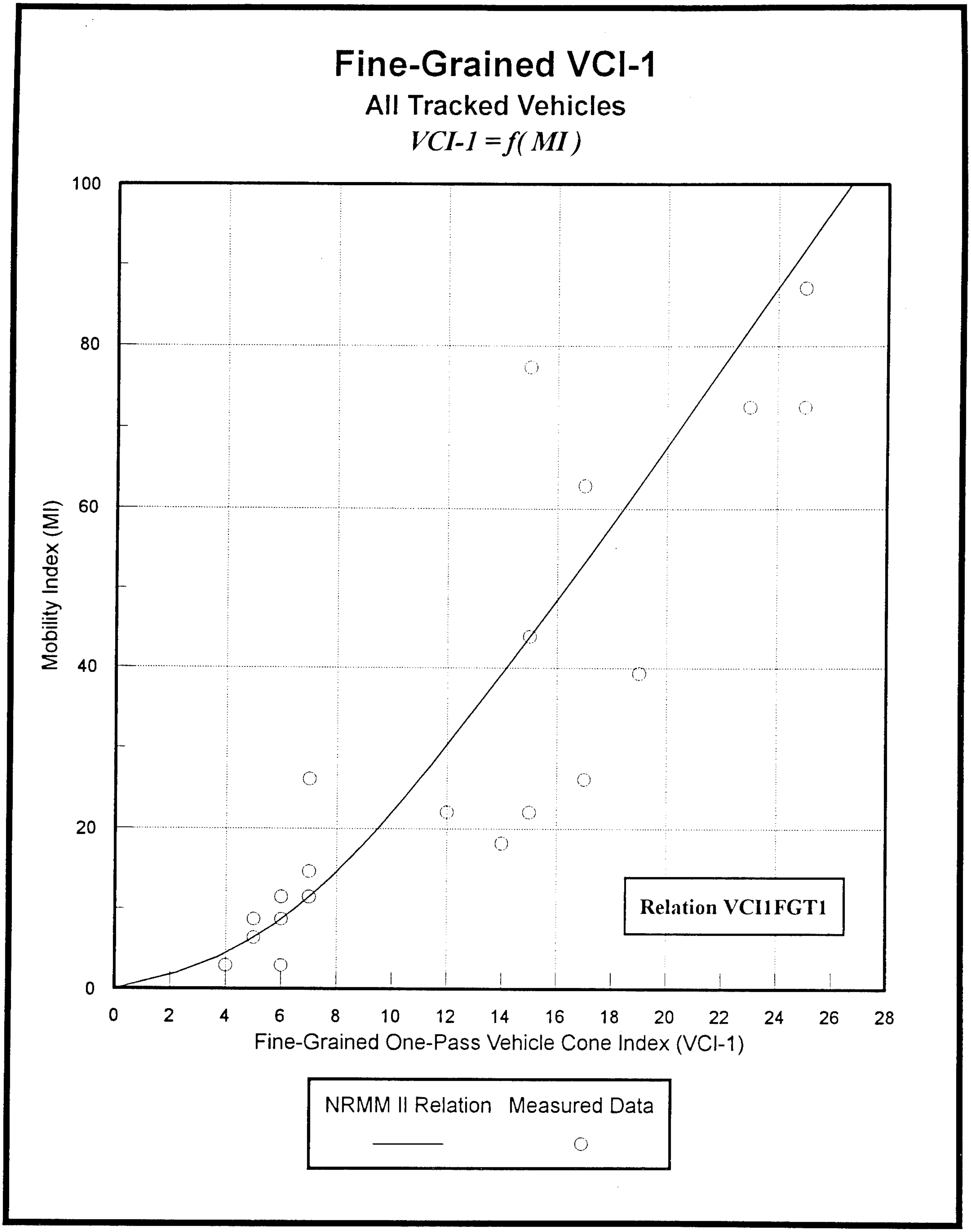
Table 29
Vehicle Configurations and Sources contained in the *Muskeg Drawbar at Nominal Slip* Database

NRMM II Relation	Vehicle	Traction Assembly Type	GVW lbf	Traction Assembly Size	CPF psi	Predicted MK VCI-1	Primary Reference Source
MK_D1	Volvo	Wheeled	4630	9.00x16	7.57	26	WES Muskeg files (B.G.S.)
MK_D1	Tree Farmer	Wheeled	14000	23.8x26	4.85	34	WES Muskeg files (B.G.S.)
MK_D1	Timberjack	Wheeled	16000	18.4x34	6.63	35	WES Muskeg files (B.G.S.)
MK_D1	Landrover	Wheeled	5000	Not Available	11.91	32	WES Muskeg files (B.G.S.)
MK_D1	M38A1	Wheeled	3465	7.00x16	8.25	24	WES Muskeg files (B.G.S.)
MK_D1	Iron Mule	Wheeled	12500	Not Available	8.94	37	WES Muskeg files (B.G.S.)
MK_D1	Land Rover Tracked	Tracked	7500	12x33 (2)	4.73	19	WES Muskeg files (B.G.S.)
MK_D1	M113	Tracked	22000	15x105	5.78	24	WES Muskeg files (B.G.S.)
MK_D2	M29C Weasel	Tracked	4919	20x78	1.58	16	WES Muskeg files (B.G.S.)
MK_D2	RAT	Tracked	2475	21x41 (2)	0.72	15	WES Muskeg files (B.G.S.)
MK_D2	XM571 Dynatrack	Tracked	7400	18x52 (2)	1.98	17	WES Muskeg files (B.G.S.)
MK_D2	Nodwell RN110	Tracked	24500	40x135	2.27	22	WES Muskeg files (B.G.S.)
MK_D2	Nodwell RN10	Tracked	3500	24x63	1.16	16	WES Muskeg files (B.G.S.)

Table 30
Vehicle Configurations and Sources contained in the *Muskeg Motion Resistance* Database

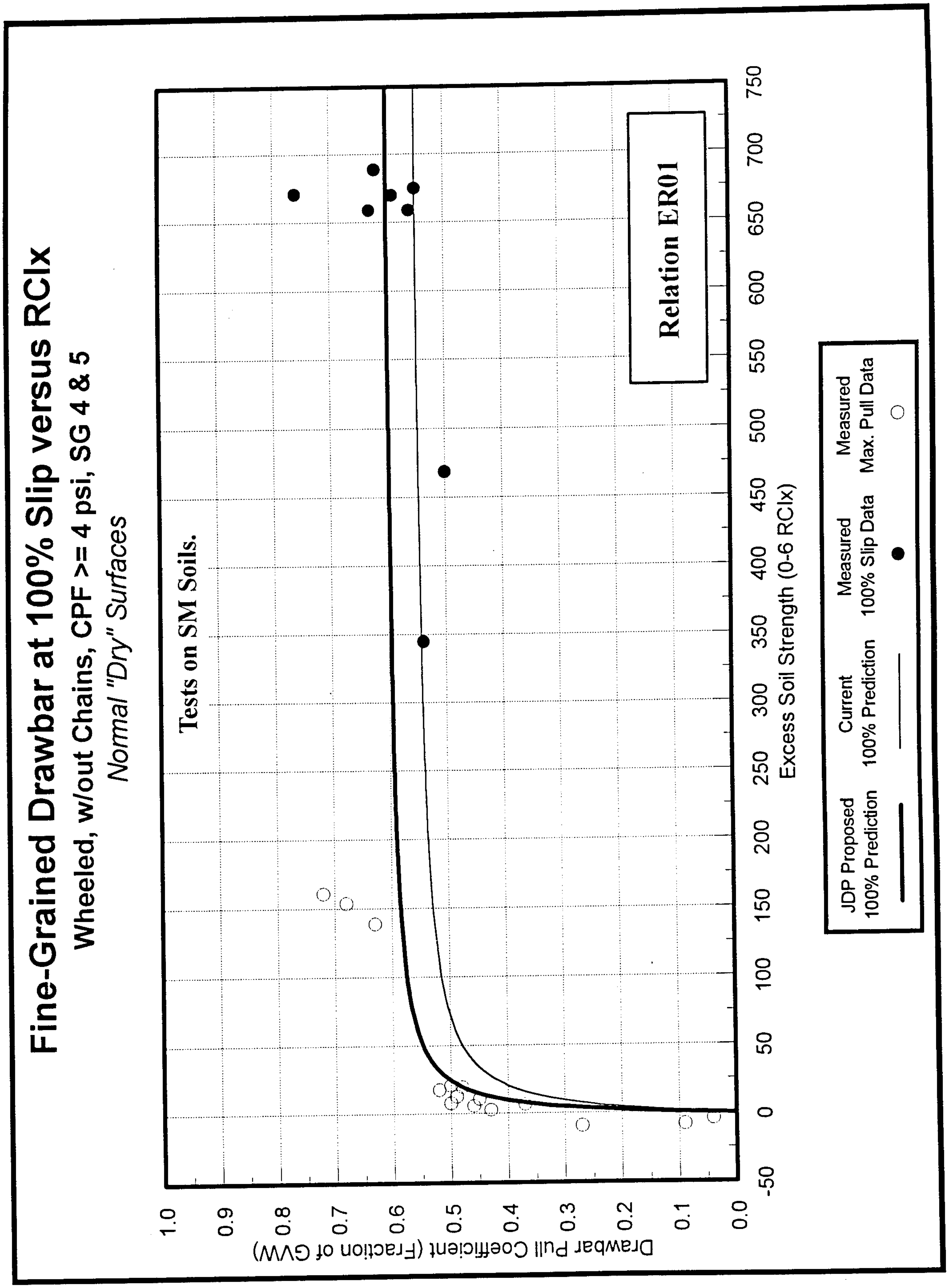
NRMM II Relation	Vehicle Identification	Traction Assembly Type	GVW lbf	Traction Assembly Size	CPF psi	Predicted MK VCI-1	Primary Reference Source
MK_T1	Nodwell RN10	Tracked	3500	24x63	1.16	16	WES Muskeg files (B.G.S.)
MK_T1	XM571 Dynatrack	Tracked	7400	18x52 (2)	1.98	17	WES Muskeg files (B.G.S.)
MK_T1	RAT	Tracked	2475	21x41 (2)	0.72	15	WES Muskeg files (B.G.S.)
MK_T1	Land Rover Tracked	Tracked	7500	12x33 (2)	4.73	19	WES Muskeg files (B.G.S.)
MK_T1	M29C Weasel	Tracked	4919	20x78	1.58	16	WES Muskeg files (B.G.S.)
MK_T1	Nodwell RN21B	Tracked	7900	28x85	1.66	17	WES Muskeg files (B.G.S.)
MK_T1	M56 Gun	Tracked	12950	20x86	3.76	21	WES Muskeg files (B.G.S.)
MK_T1	Volvo	Wheeled	4630	9.00x16	7.57	26	WES Muskeg files (B.G.S.)
MK_T1	Tree Farmer	Wheeled	14000	23.8x26	4.85	34	WES Muskeg files (B.G.S.)
MK_T1	Timberjack	Wheeled	16000	18.4x34	6.63	35	WES Muskeg files (B.G.S.)
MK_T1	Landrover	Wheeled	5000	Not Available	11.91	32	WES Muskeg files (B.G.S.)
MK_T1	M38A1	Wheeled	3465	7.00x16	8.25	24	WES Muskeg files (B.G.S.)
MK_T1	Iron Mule	Wheeled	12500	Not Available	8.94	37	WES Muskeg files (B.G.S.)


Fine-Grained VCI-1
All Wheeled Vehicles
VCI-1 = f(MI)
Mobility Index (MI)
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
$VCI_{1(FG)} / \left[\frac{0.15}{\delta/h}\right]^{0.25}$
Relation VCI1FGW1
NRMM II Relation
Measured Data



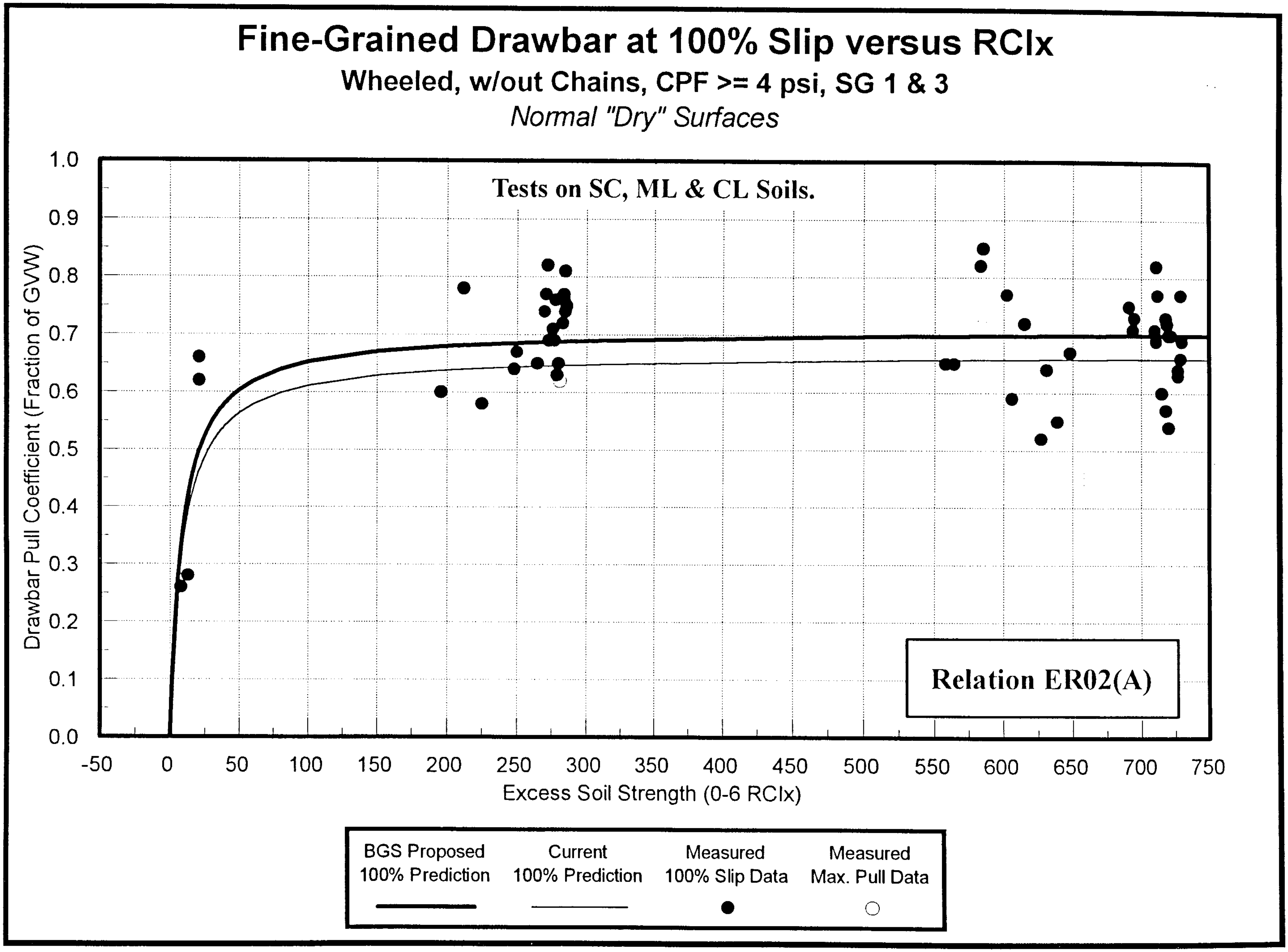
Fine-Grained VCI-1
All Tracked Vehicles
VCI-1 = f(MI)
Mobility Index (MI)
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Fine-Grained One-Pass Vehicle Cone Index (VCI-1)
Relation VCI1FGT1
NRMM II Relation
Measured Data

Plate 2

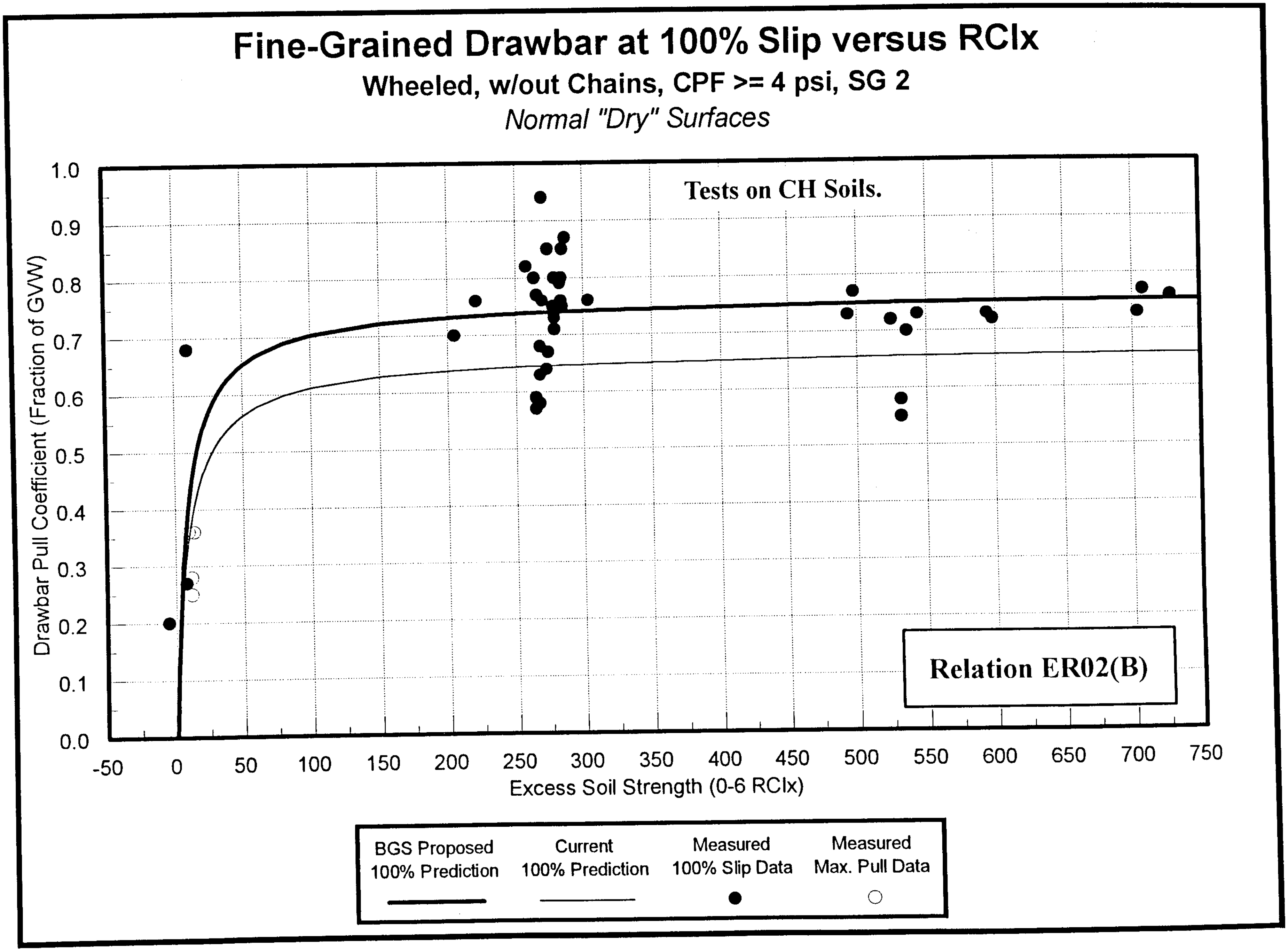


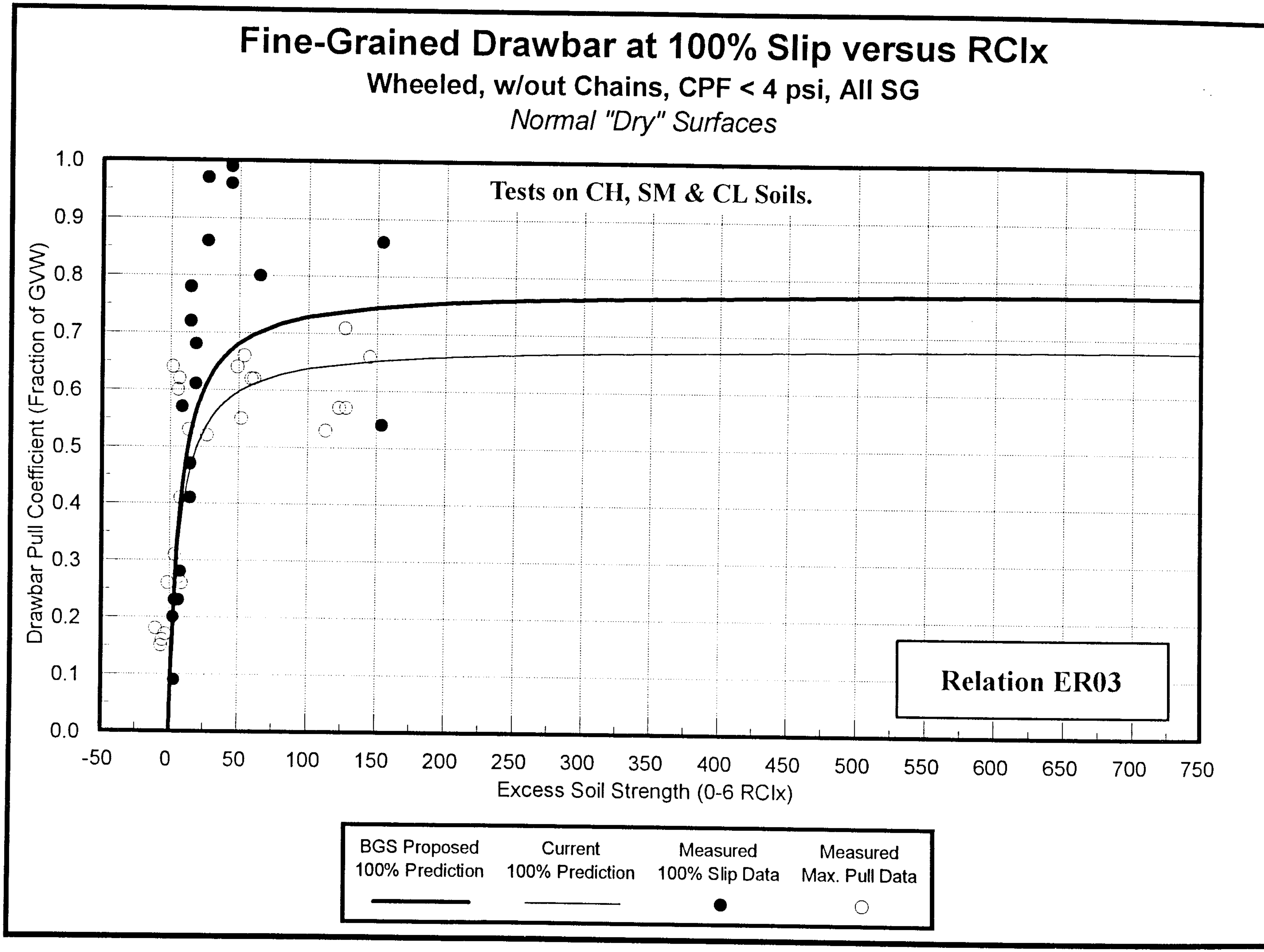
Fine-Grained Drawbar at 100% Slip versus RCIx
Wheeled, w/out Chains, CPF >= 4 psi, SG 4 & 5
Normal "Dry" Surfaces
Tests on SM Soils.
Relation ER01
Drawbar Pull Coefficient (Fraction of GVW)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Excess Soil Strength (0-6 RCIx)
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
JDP Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data
Measured Max. Pull Data

Plate 3

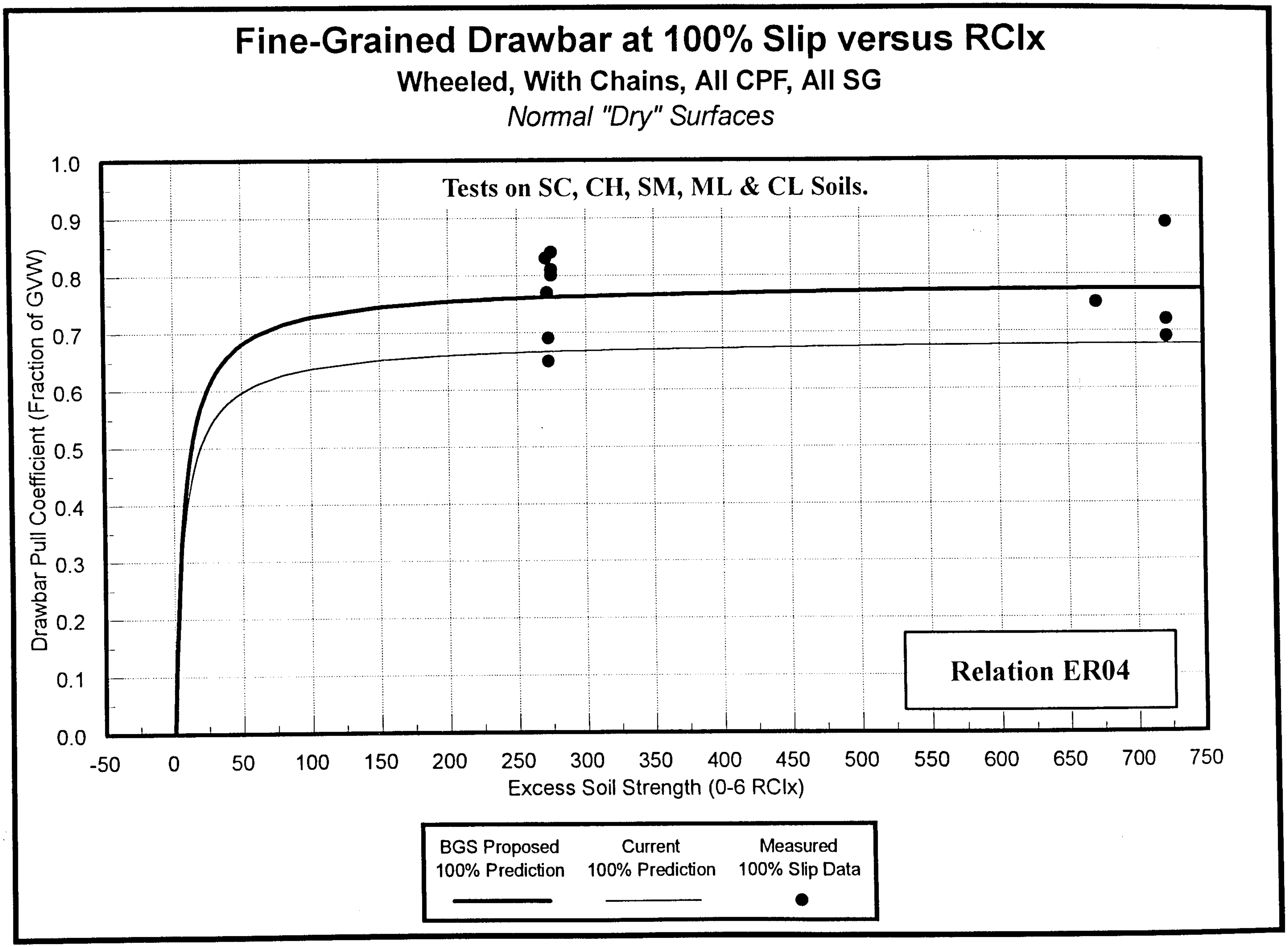


Fine-Grained Drawbar at 100% Slip versus RCIx
Wheeled, w/out Chains, CPF >= 4 psi, SG 1 & 3
Normal "Dry" Surfaces
Tests on SC, ML & CL Soils.
Relation ER02(A)
Drawbar Pull Coefficient (Fraction of GVW)
Excess Soil Strength (0-6 RCIx)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
BGS Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data
Measured Max. Pull Data

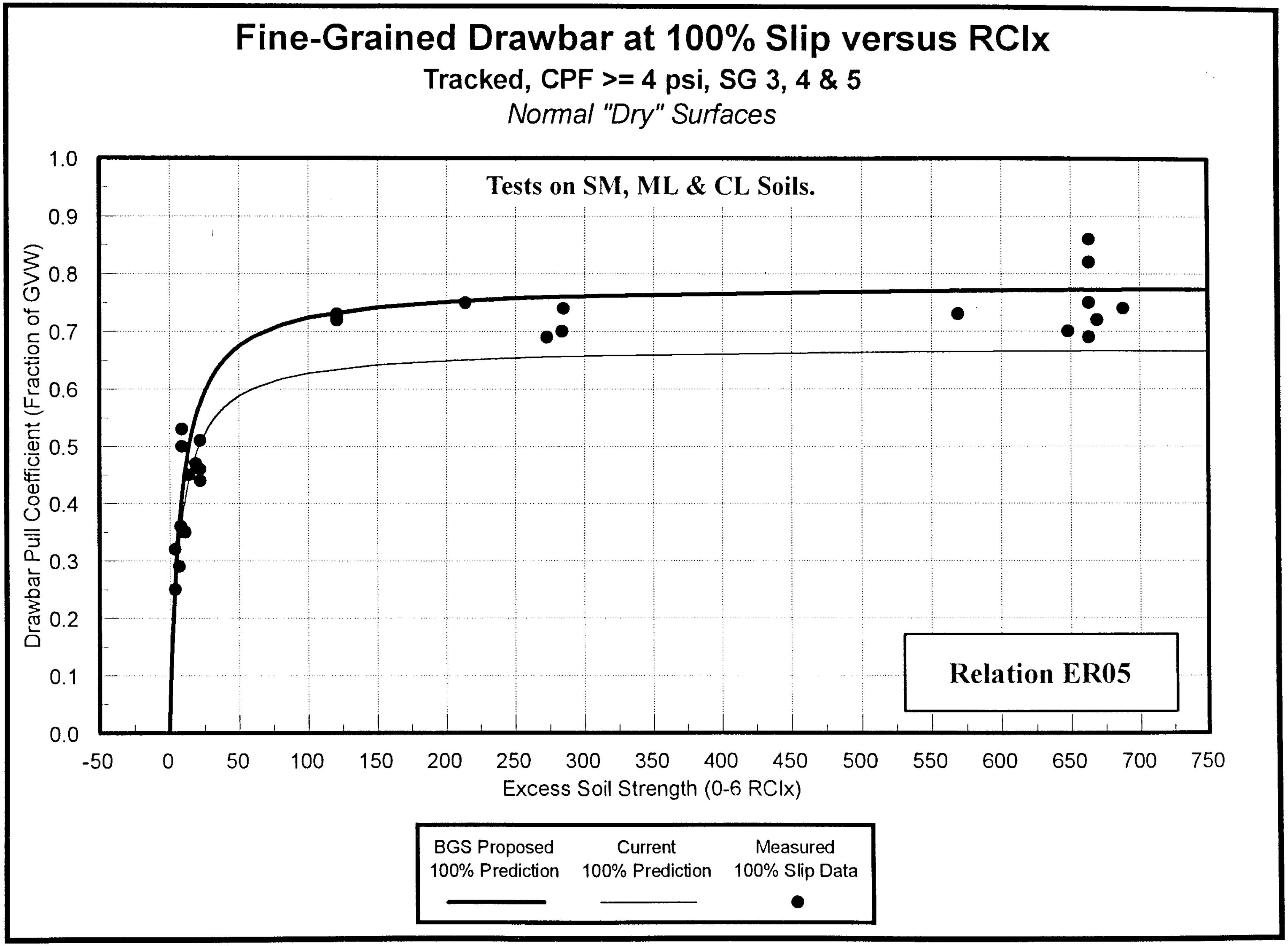

Fine-Grained Drawbar at 100% Slip versus RClx
Wheeled, w/out Chains, CPF >= 4 psi, SG 2
Normal "Dry" Surfaces
Tests on CH Soils.
Relation ER02(B)
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RClx)
BGS Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data
Measured Max. Pull Data



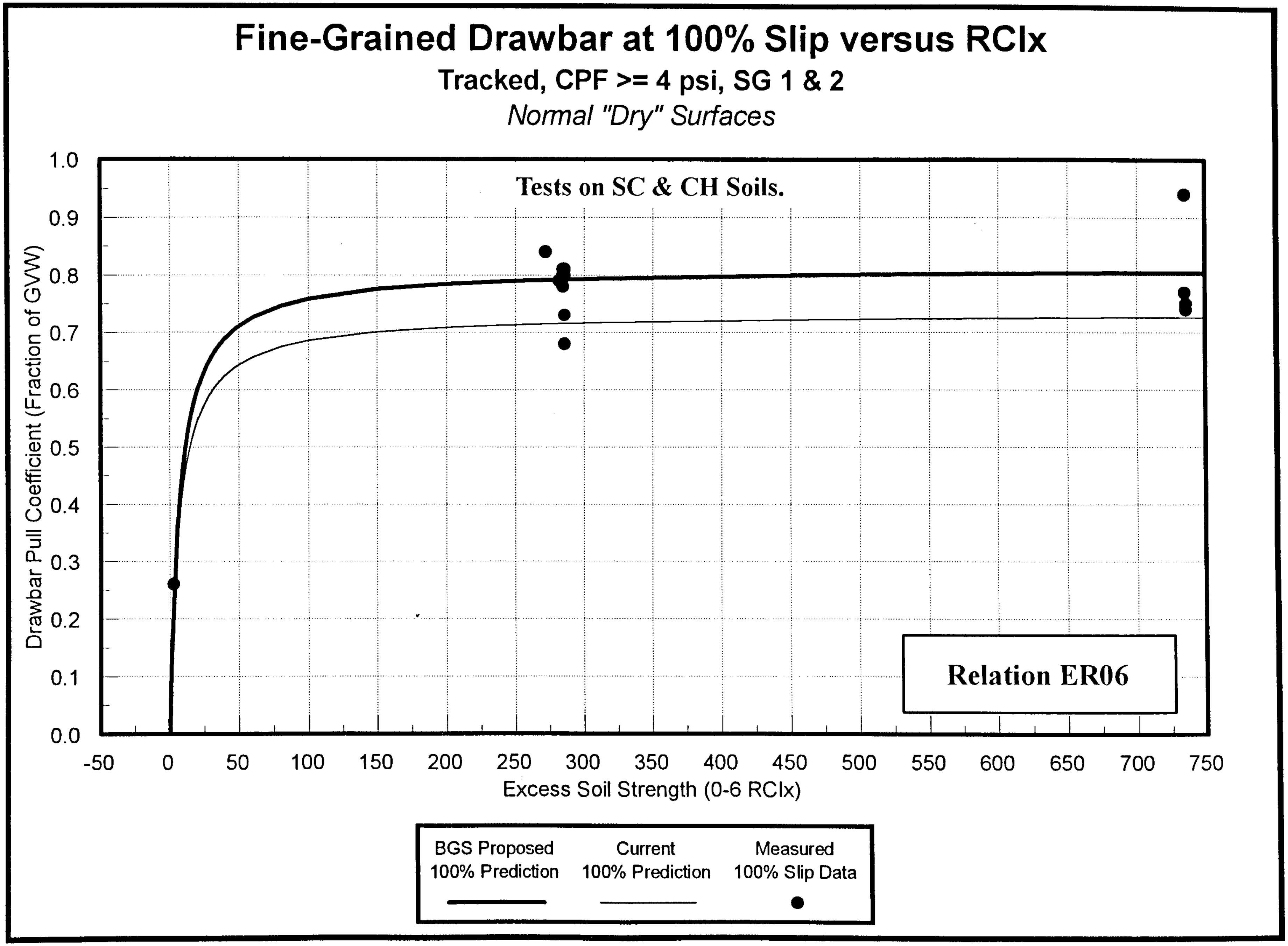
Fine-Grained Drawbar at 100% Slip versus RCIx
Wheeled, w/out Chains, CPF < 4 psi, All SG
Normal "Dry" Surfaces
Tests on CH, SM & CL Soils.
Relation ER03
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data
Measured Max. Pull Data



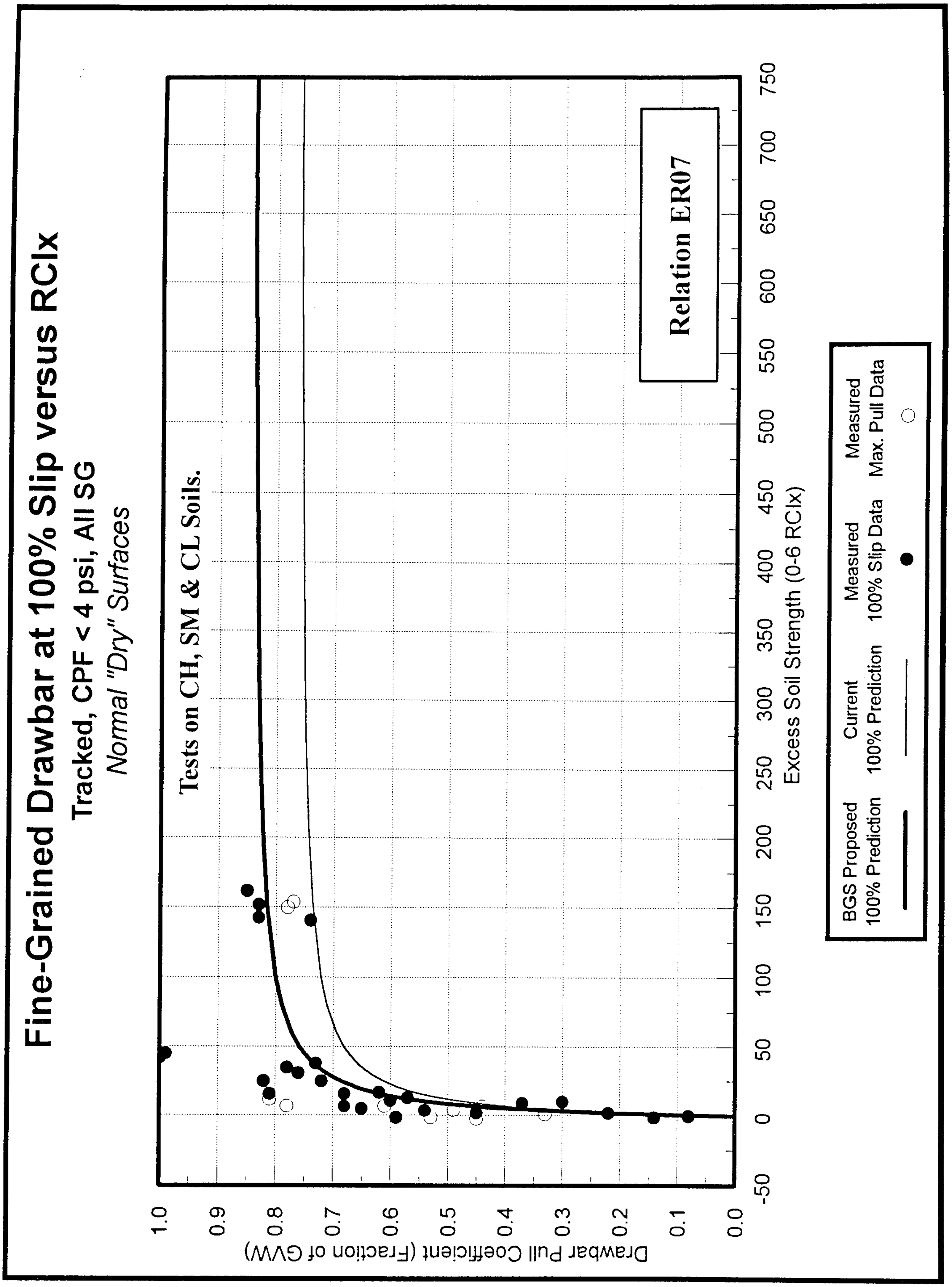
Fine-Grained Drawbar at 100% Slip versus RCIx
Wheeled, With Chains, All CPF, All SG
Normal "Dry" Surfaces
Tests on SC, CH, SM, ML & CL Soils.
Relation ER04
Drawbar Pull Coefficient (Fraction of GVW)
Excess Soil Strength (0-6 RCIx)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
BGS Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data



Fine-Grained Drawbar at 100% Slip versus RCIx
Tracked, CPF >= 4 psi, SG 3, 4 & 5
Normal "Dry" Surfaces
Tests on SM, ML & CL Soils.
Relation ER05
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed
100% Prediction
Current
100% Prediction
Measured
100% Slip Data

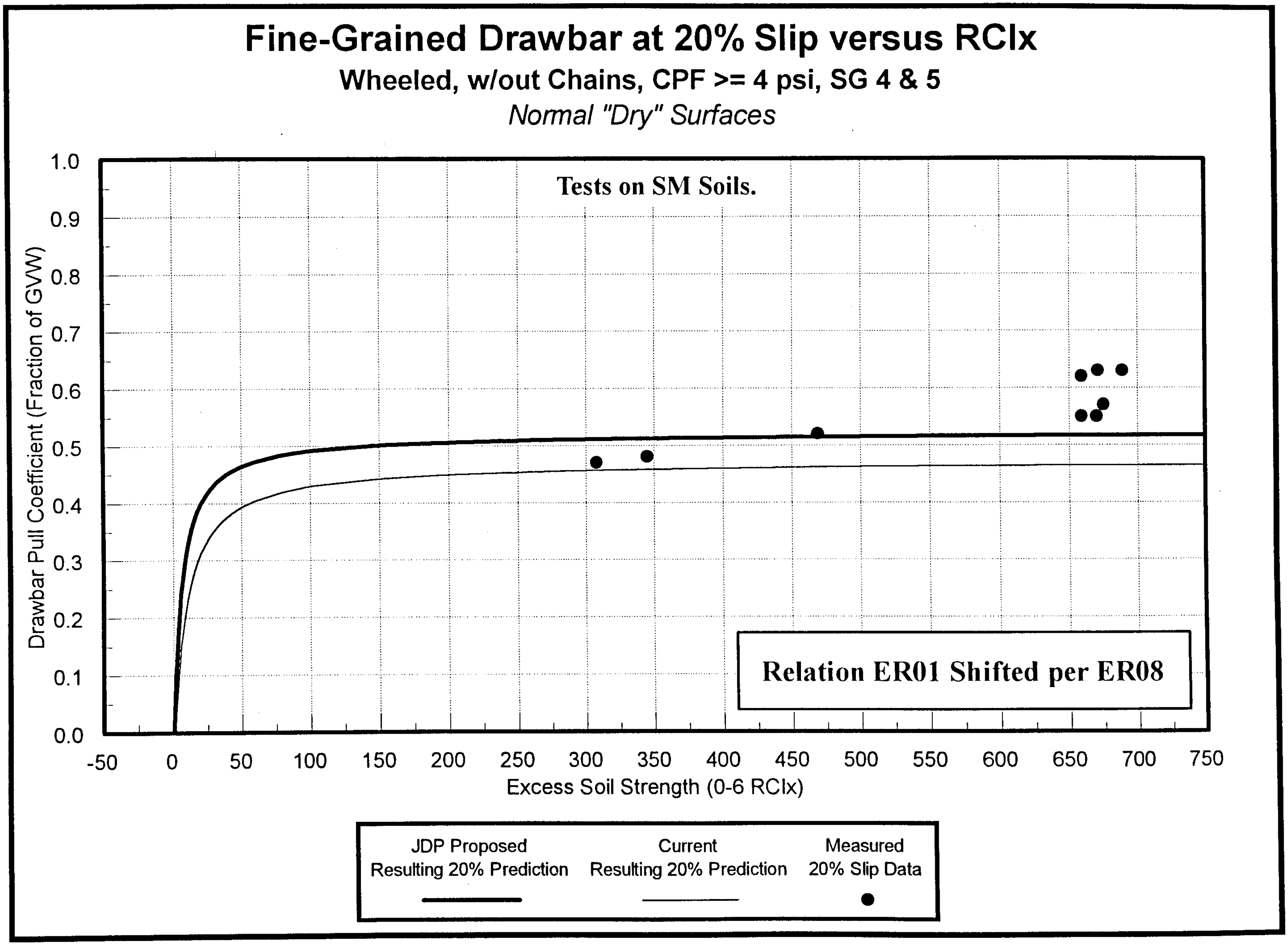


Fine-Grained Drawbar at 100% Slip versus RCIx
Tracked, CPF >= 4 psi, SG 1 & 2
Normal "Dry" Surfaces
Tests on SC & CH Soils.
Relation ER06
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed 100% Prediction
Current 100% Prediction
Measured 100% Slip Data

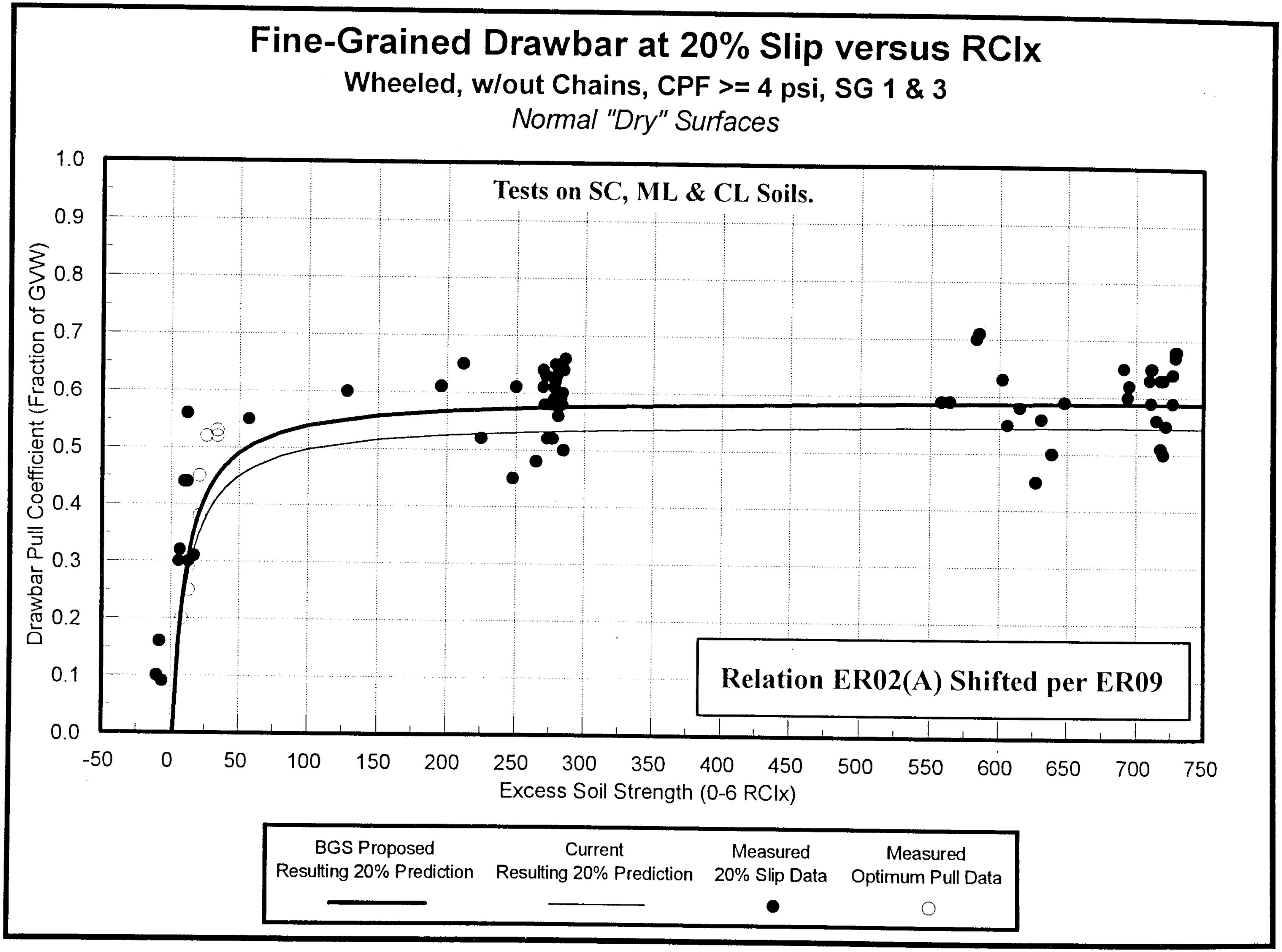


Fine-Grained Drawbar at 100% Slip versus RCIx
Tracked, CPF < 4 psi, All SG
Normal "Dry" Surfaces
Tests on CH, SM & CL Soils.
Relation ER07
Drawbar Pull Coefficient (Fraction of GVW)
Excess Soil Strength (0-6 RCIx)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
BGS Proposed
100% Prediction
Current
100% Prediction
Measured
100% Slip Data
Measured
Max. Pull Data

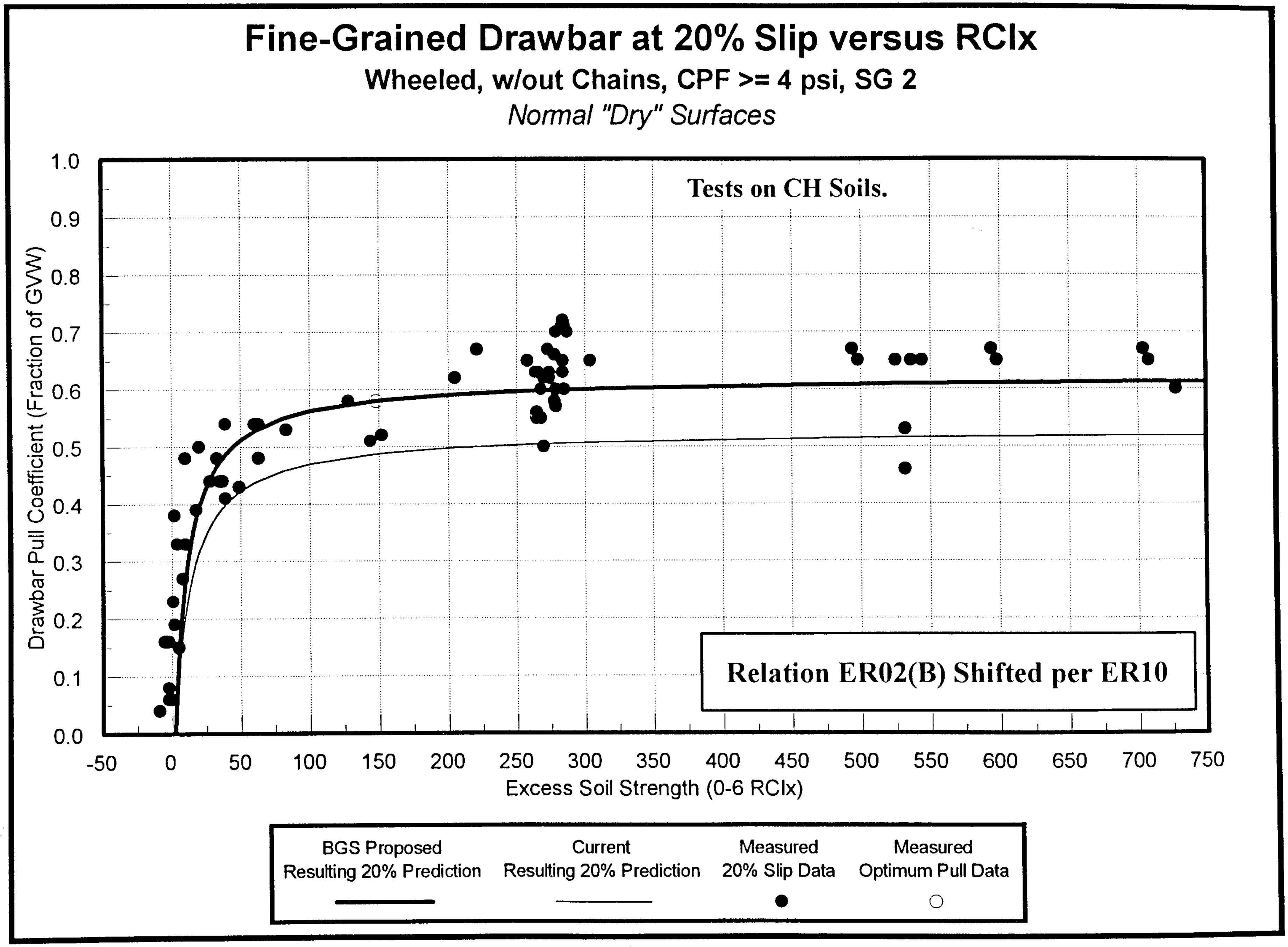
Plate 10



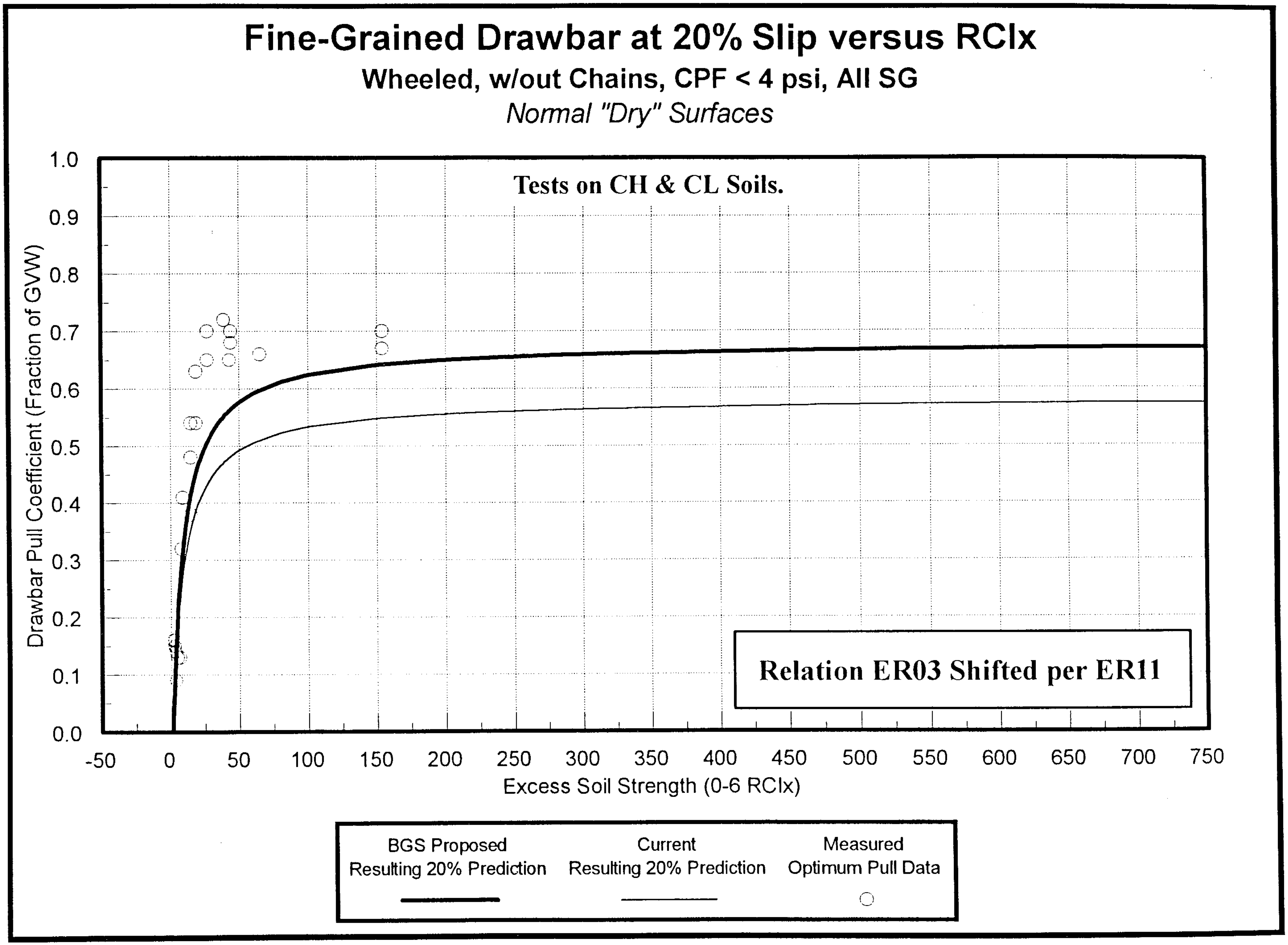
Fine-Grained Drawbar at 20% Slip versus RCIx
Wheeled, w/out Chains, CPF >= 4 psi, SG 4 & 5
Normal "Dry" Surfaces
Tests on SM Soils.
Relation ER01 Shifted per ER08
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
JDP Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data



Fine-Grained Drawbar at 20% Slip versus RCIx
Wheeled, w/out Chains, CPF >= 4 psi, SG 1 & 3
Normal "Dry" Surfaces
Tests on SC, ML & CL Soils.
Relation ER02(A) Shifted per ER09
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data
Measured Optimum Pull Data



Fine-Grained Drawbar at 20% Slip versus RCIx
Wheeled, w/out Chains, CPF >= 4 psi, SG 2
Normal "Dry" Surfaces
Tests on CH Soils.
Relation ER02(B) Shifted per ER10
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data
Measured Optimum Pull Data

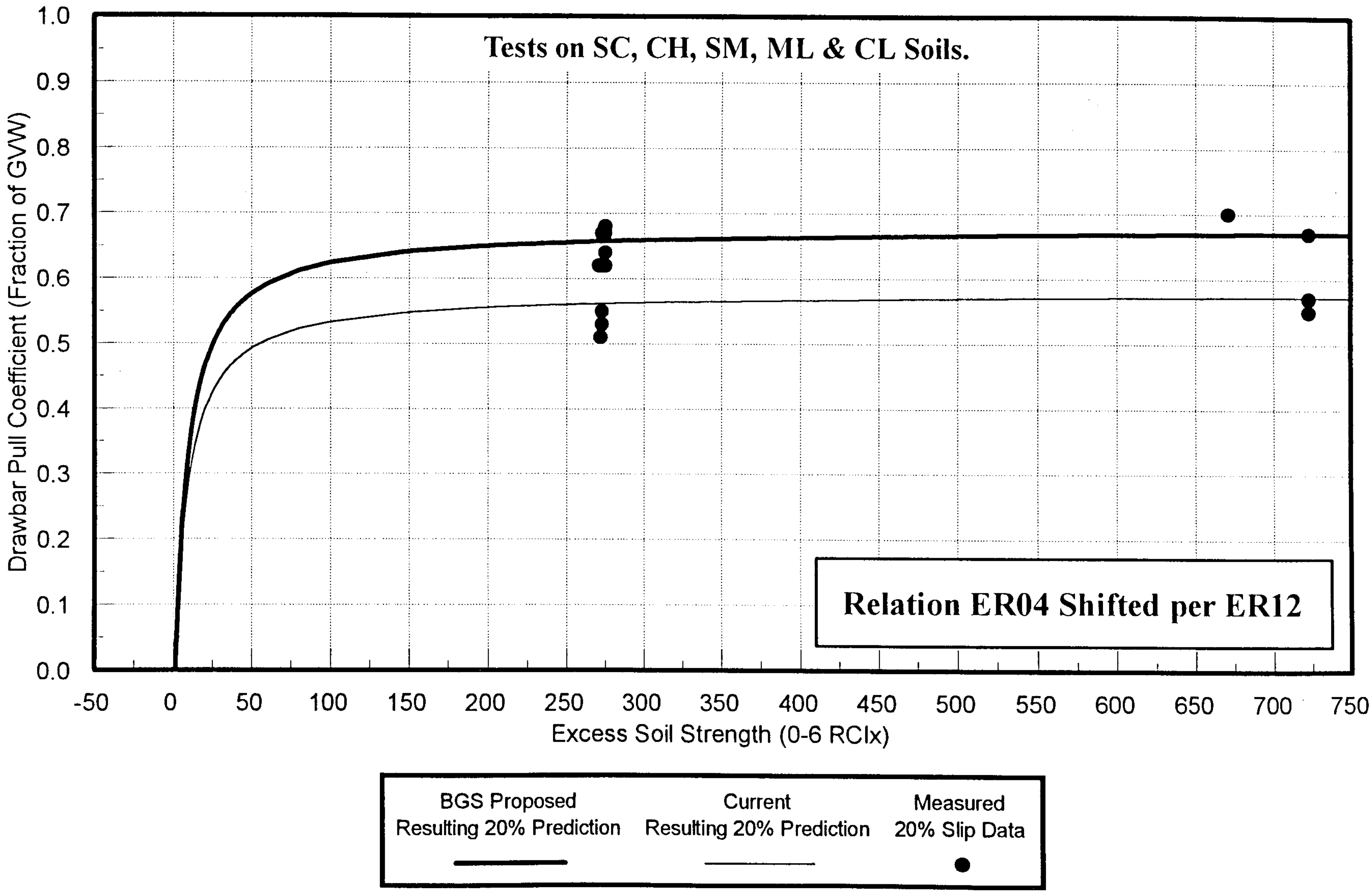


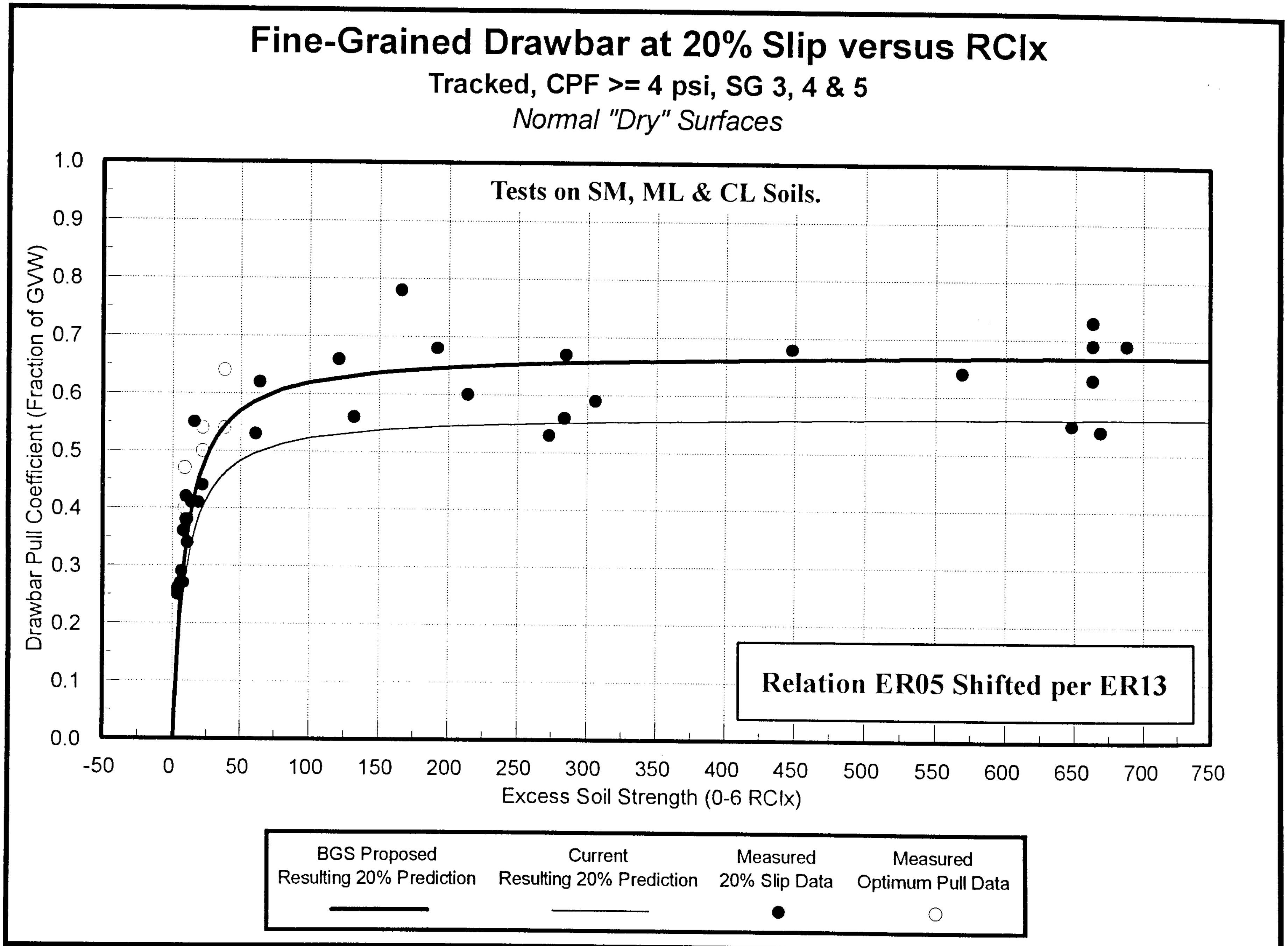
Fine-Grained Drawbar at 20% Slip versus RCIx
Wheeled, w/out Chains, CPF < 4 psi, All SG
Normal "Dry" Surfaces
Tests on CH & CL Soils.
Relation ER03 Shifted per ER11
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured Optimum Pull Data

Fine-Grained Drawbar at 20% Slip versus RCIx

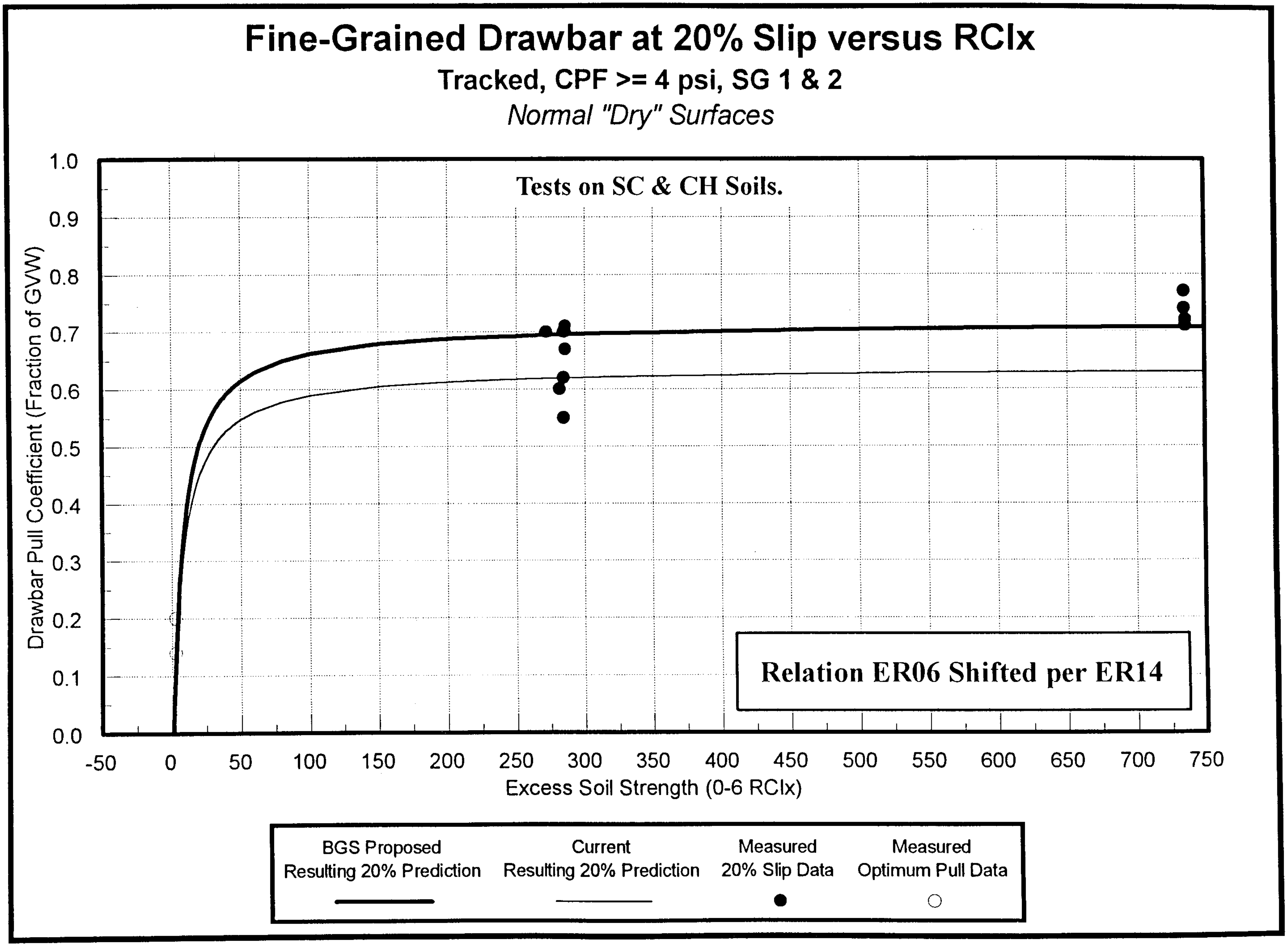
Wheeled, With Chains, All CPF, All SG

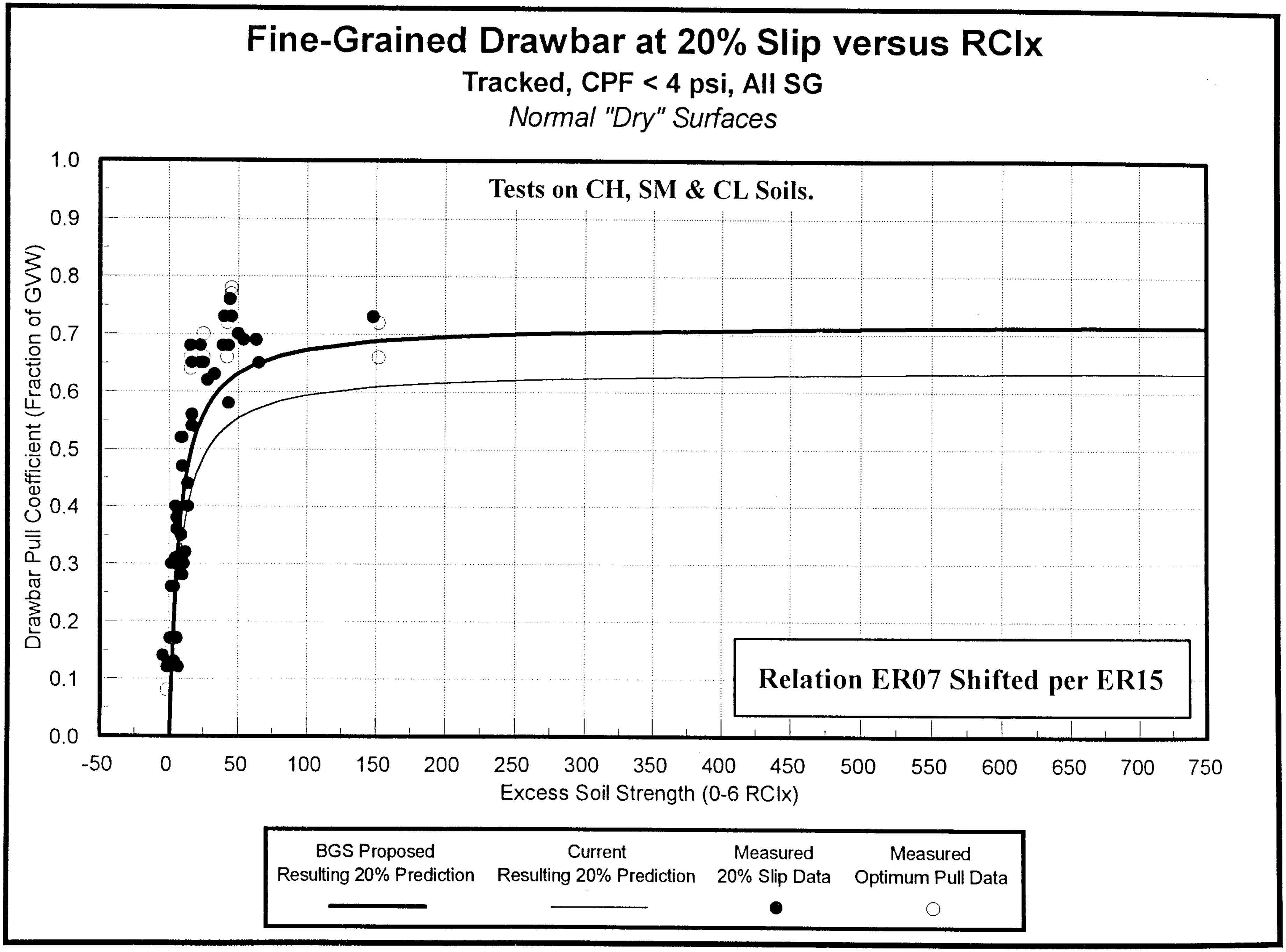
Normal "Dry" Surfaces

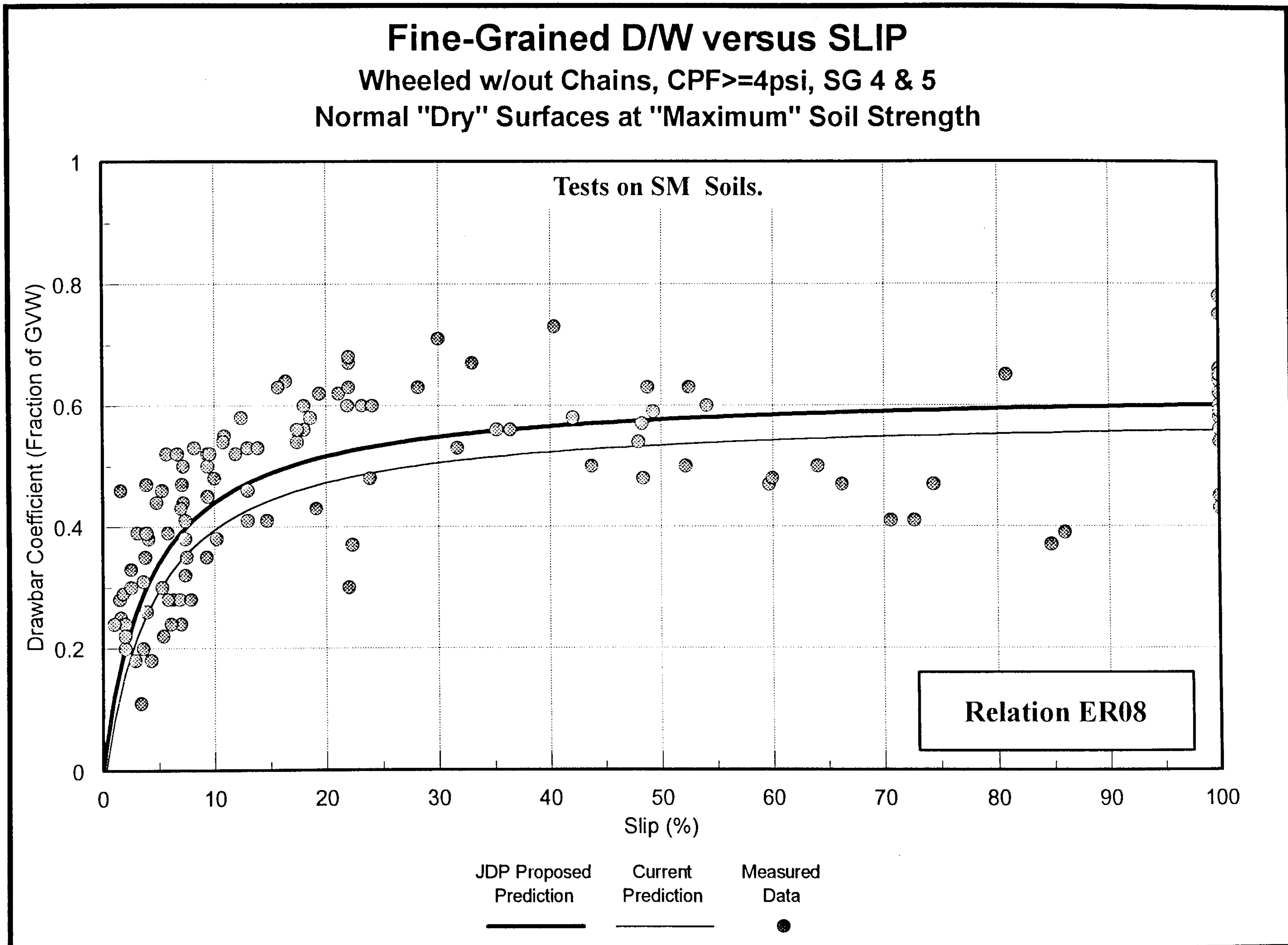




Fine-Grained Drawbar at 20% Slip versus RCIx
Tracked, CPF >= 4 psi, SG 3, 4 & 5
Normal "Dry" Surfaces
Tests on SM, ML & CL Soils.
Relation ER05 Shifted per ER13
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data
Measured Optimum Pull Data


Fine-Grained Drawbar at 20% Slip versus RCIx
Tracked, CPF >= 4 psi, SG 1 & 2
Normal "Dry" Surfaces
Tests on SC & CH Soils.
Relation ER06 Shifted per ER14
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data
Measured Optimum Pull Data


Fine-Grained Drawbar at 20% Slip versus RCIx
Tracked, CPF < 4 psi, All SG
Normal "Dry" Surfaces
Tests on CH, SM & CL Soils.
Relation ER07 Shifted per ER15
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
BGS Proposed Resulting 20% Prediction
Current Resulting 20% Prediction
Measured 20% Slip Data
Measured Optimum Pull Data



Fine-Grained D/W versus SLIP
Wheeled w/out Chains, CPF>=4psi, SG 4 & 5
Normal "Dry" Surfaces at "Maximum" Soil Strength
Tests on SM Soils.
Relation ER08
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
Slip (%)
0
10
20
30
40
50
60
70
80
90
100
JDP Proposed Prediction
Current Prediction
Measured Data

Fine-Grained D/W versus SLIP

Wheeled w/out Chains, CPF>=4psi, SG 1 & 3
Normal "Dry" Surfaces at "Maximum" Soil Strength

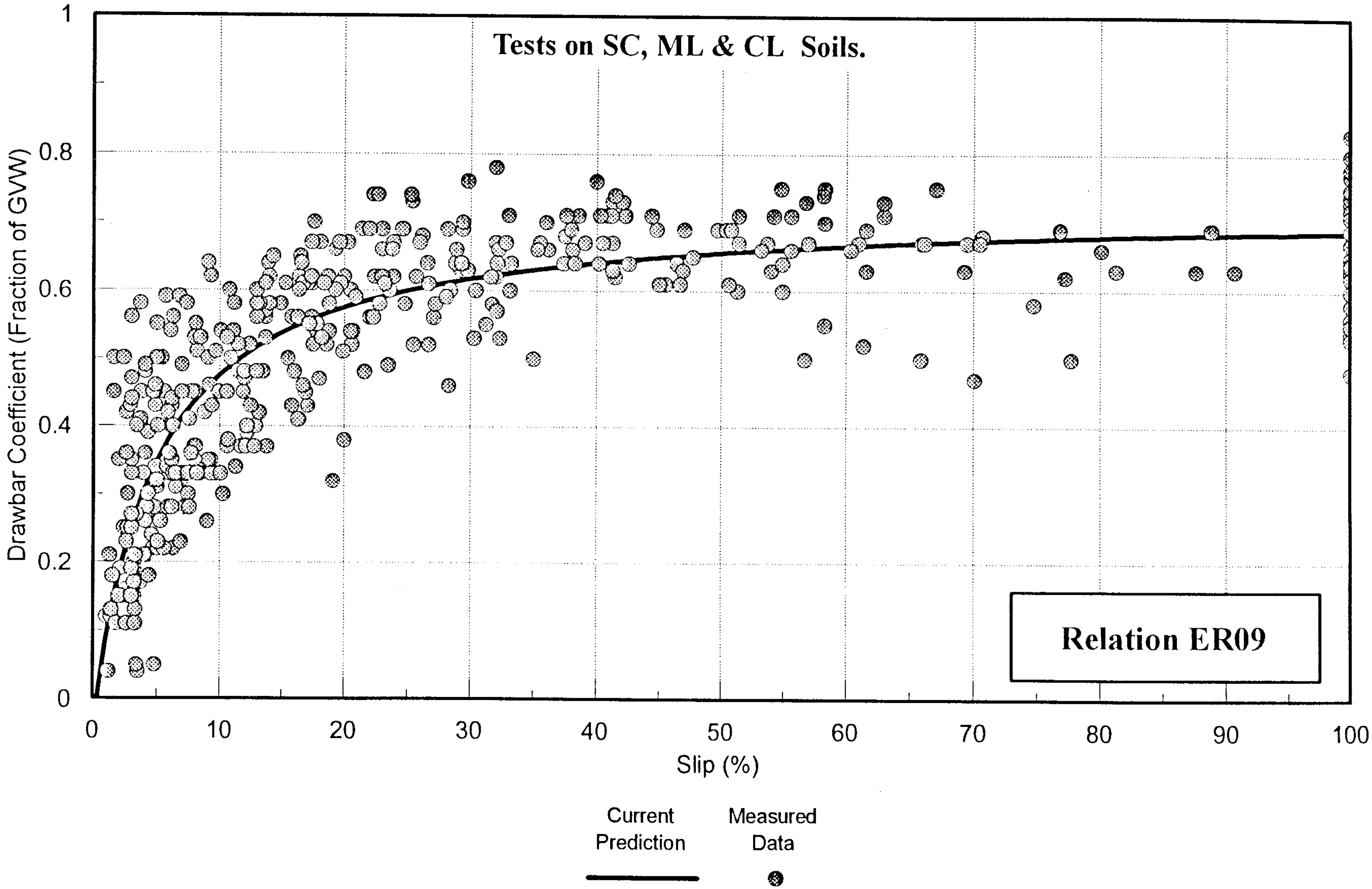
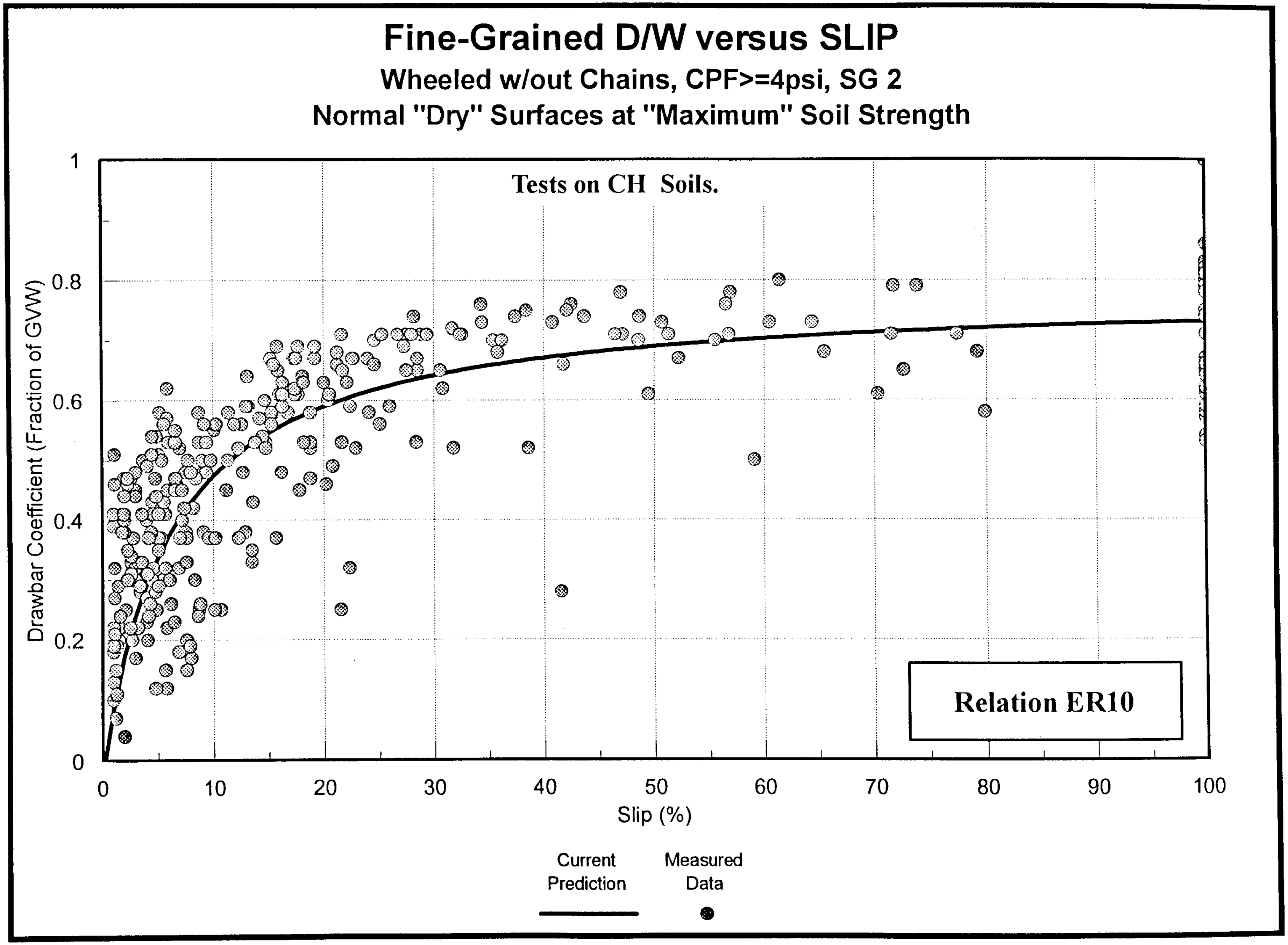


Plate 20


Fine-Grained D/W versus SLIP
Wheeled w/out Chains, CPF>=4psi, SG 2
Normal "Dry" Surfaces at "Maximum" Soil Strength
Tests on CH Soils.
Drawbar Coefficient (Fraction of GVW)
Slip (%)
Relation ER10
Current Prediction
Measured Data
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100

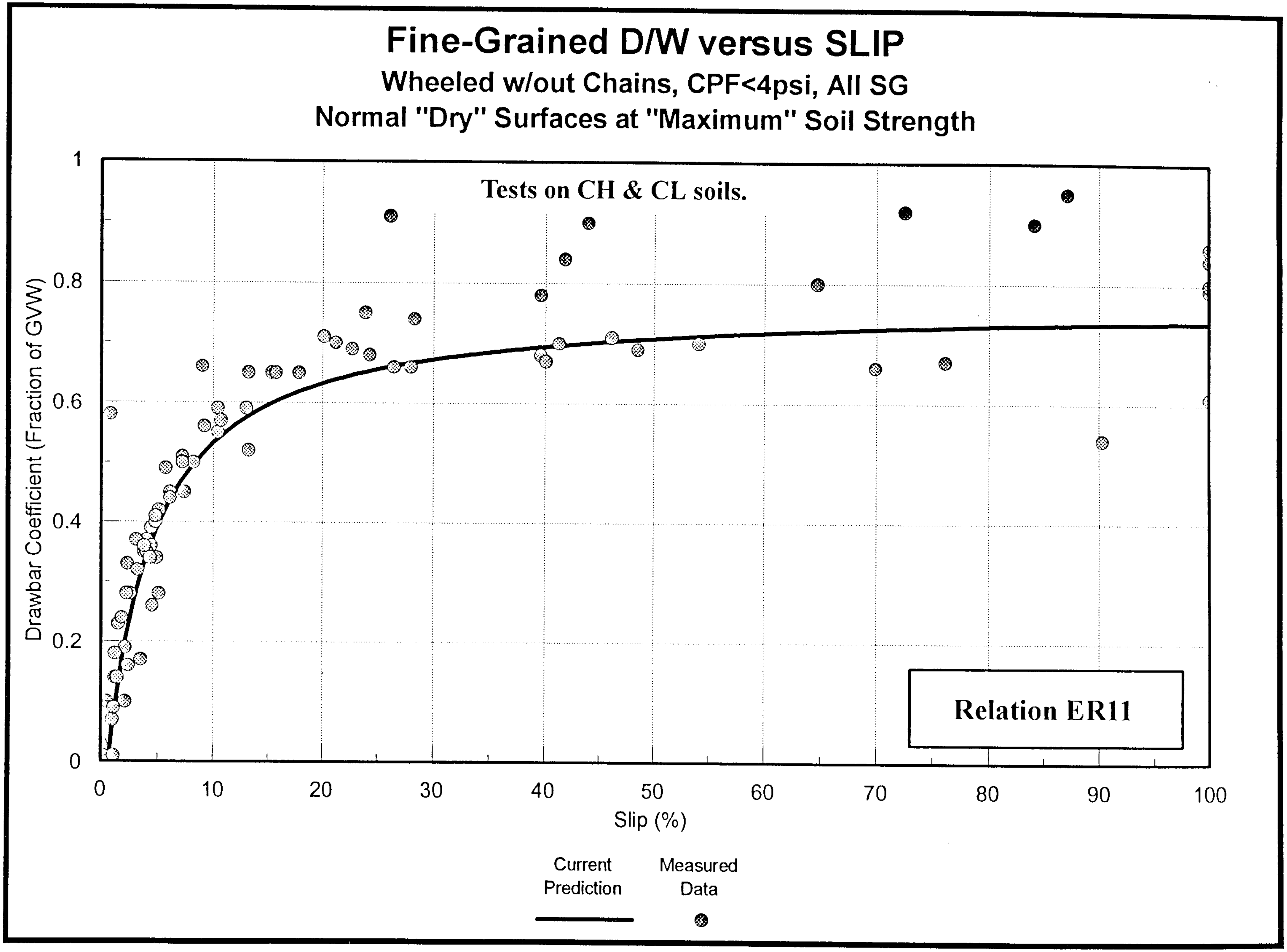
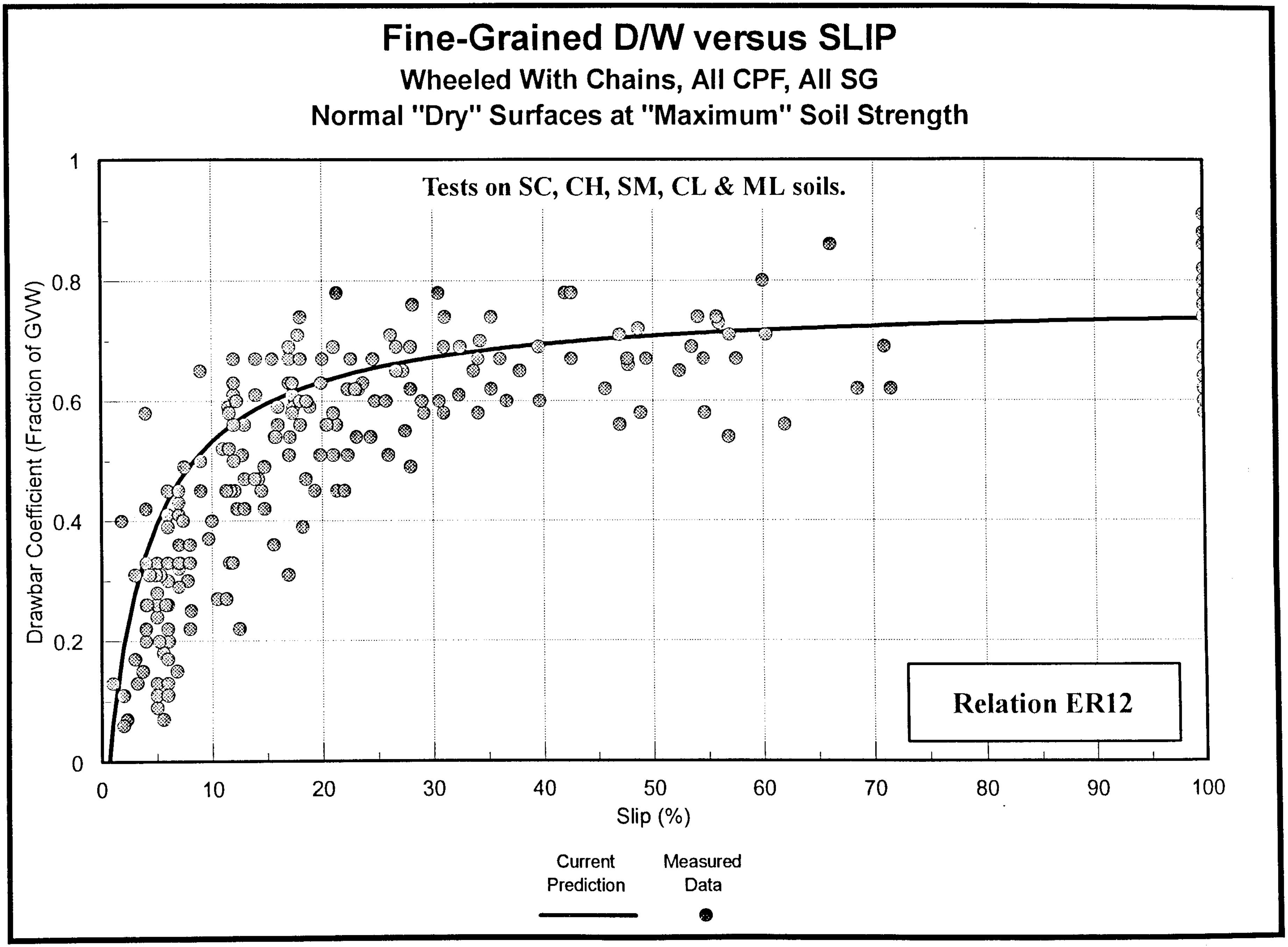
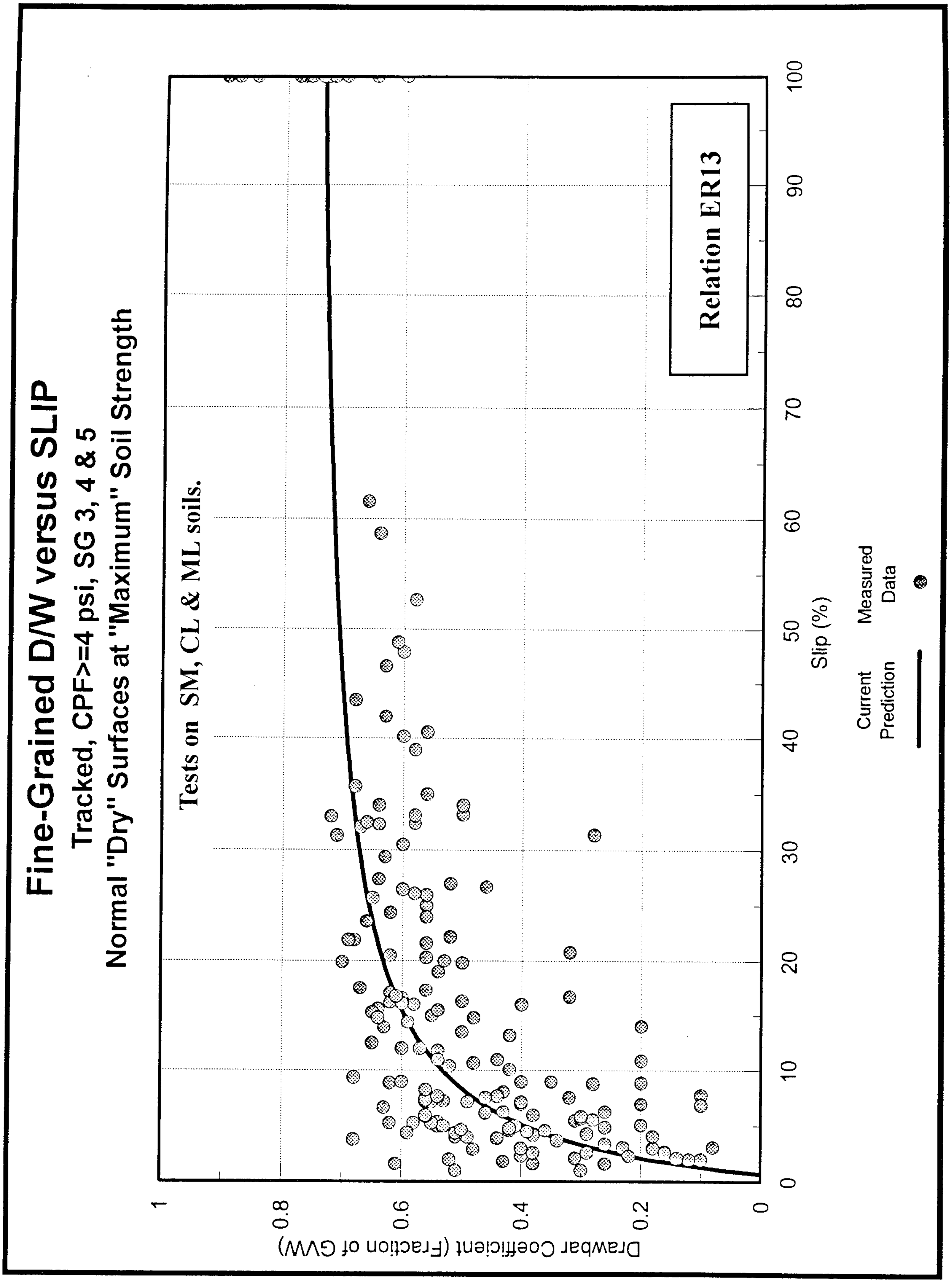

Fine-Grained D/W versus SLIP
Wheeled w/out Chains, CPF<4psi, All SG
Normal "Dry" Surfaces at "Maximum" Soil Strength
Tests on CH & CL soils.
Relation ER11
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
Slip (%)
0
10
20
30
40
50
60
70
80
90
100
Current Prediction
Measured Data

Plate 22



Fine-Grained D/W versus SLIP
Wheeled With Chains, All CPF, All SG
Normal "Dry" Surfaces at "Maximum" Soil Strength
Tests on SC, CH, SM, CL & ML soils.
Relation ER12
Drawbar Coefficient (Fraction of GVW)
Slip (%)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Current Prediction
Measured Data

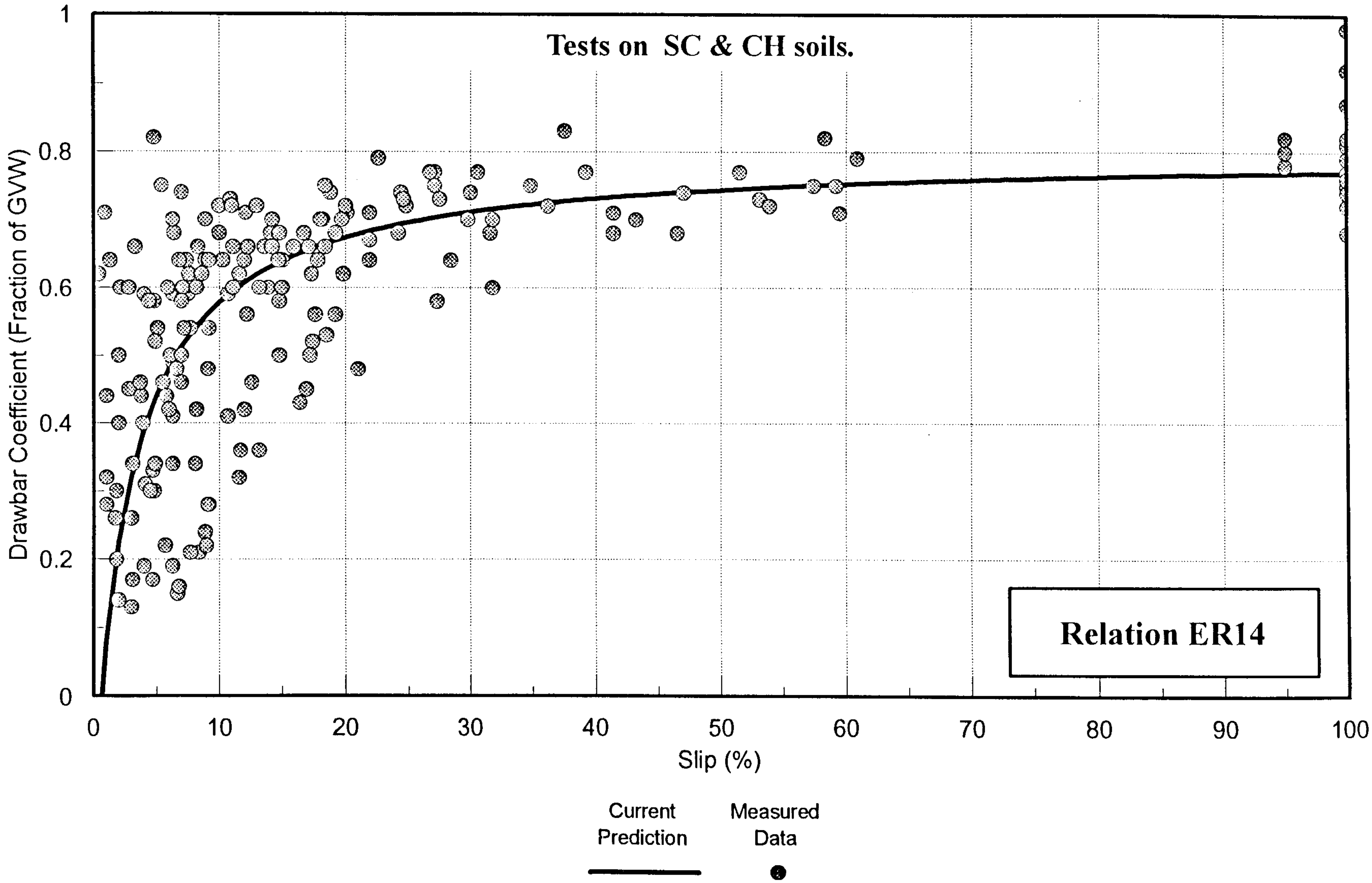


Fine-Grained D/W versus SLIP
Tracked, CPF>=4 psi, SG 3, 4 & 5
Normal "Dry" Surfaces at "Maximum" Soil Strength
Tests on SM, CL & ML soils.
Relation ER13
Drawbar Coefficient (Fraction of GVW)
Slip (%)
Current Prediction
Measured Data
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100

Fine-Grained D/W versus SLIP

Tracked, CPF>=4 psi, SG 1 & 2

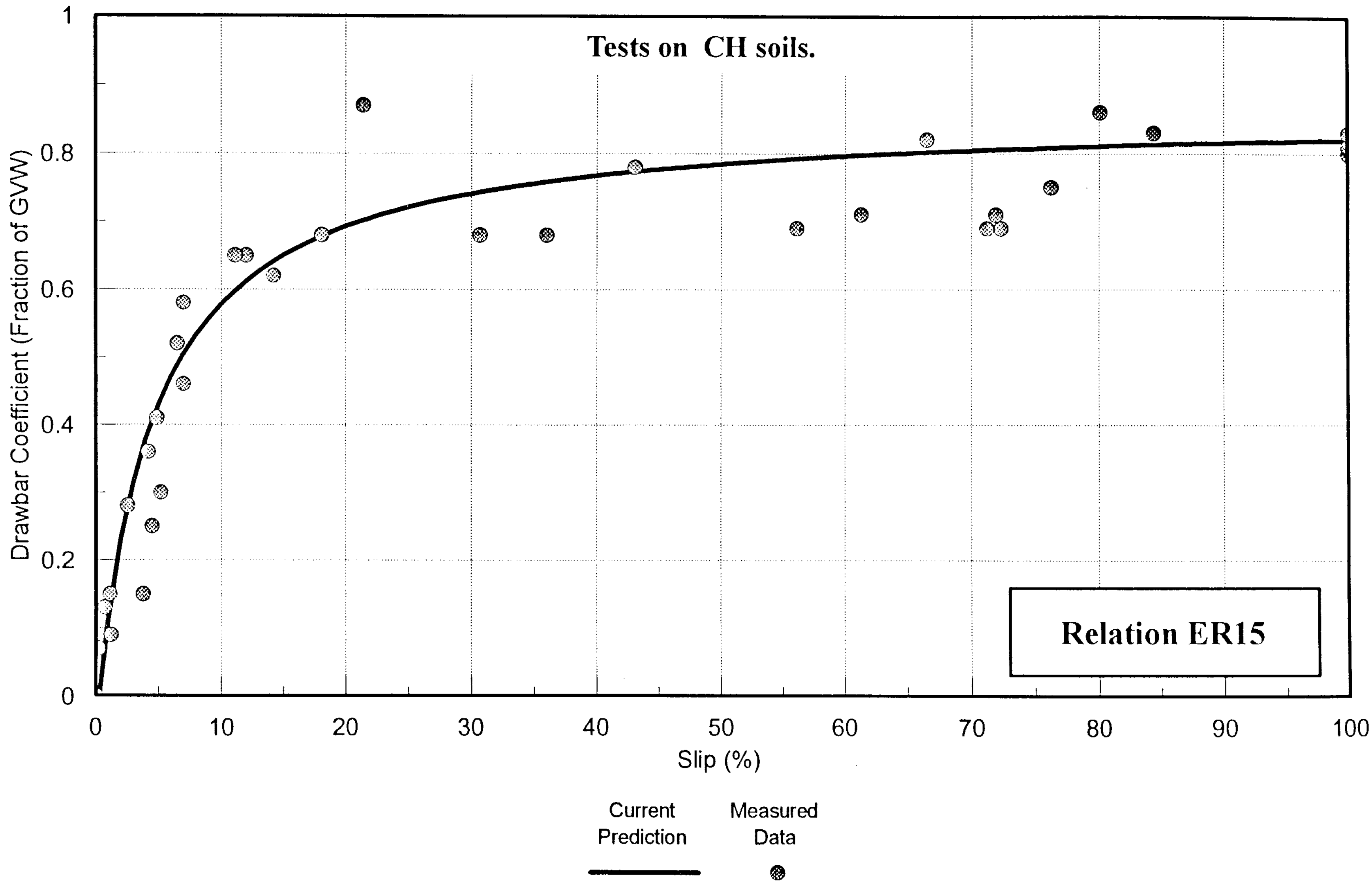
Normal "Dry" Surfaces at "Maximum" Soil Strength

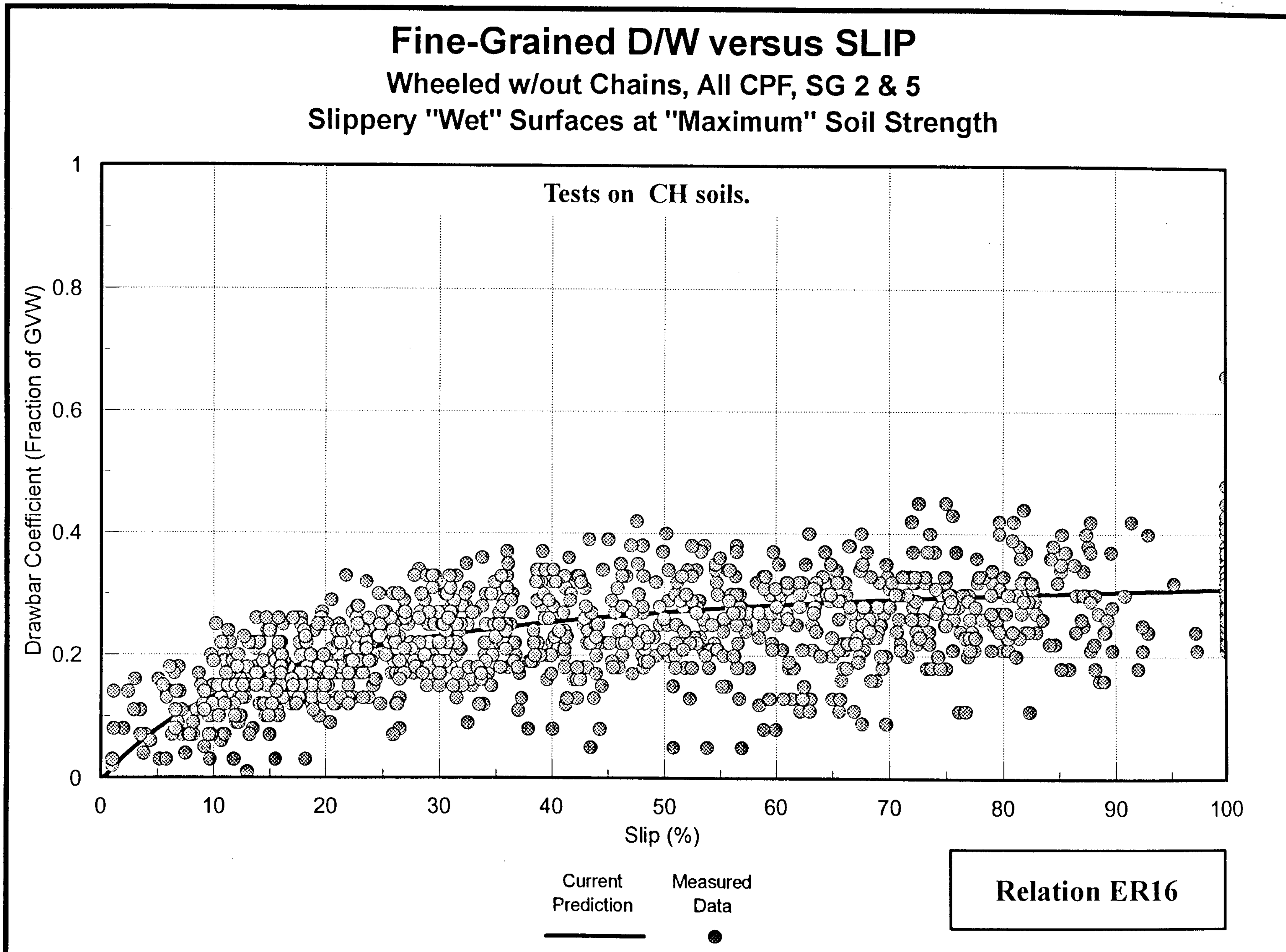


Fine-Grained D/W versus SLIP

Tracked, CPF<4 psi, All SG

Normal "Dry" Surfaces at "Maximum" Soil Strength



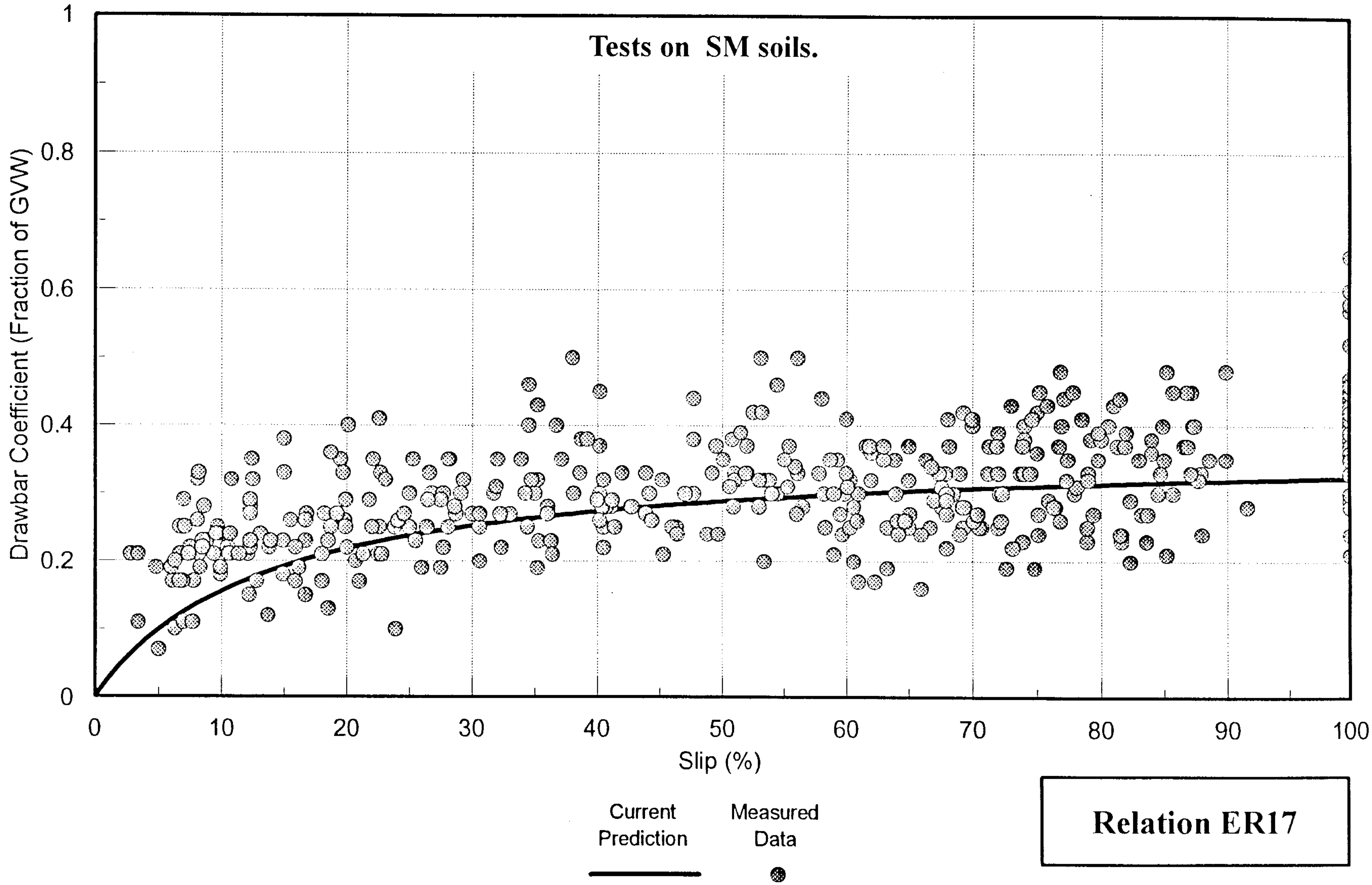


Fine-Grained D/W versus SLIP
Wheeled w/out Chains, All CPF, SG 2 & 5
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CH soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER16

Fine-Grained D/W versus SLIP

Wheeled w/out Chains, All CPF, SG 4

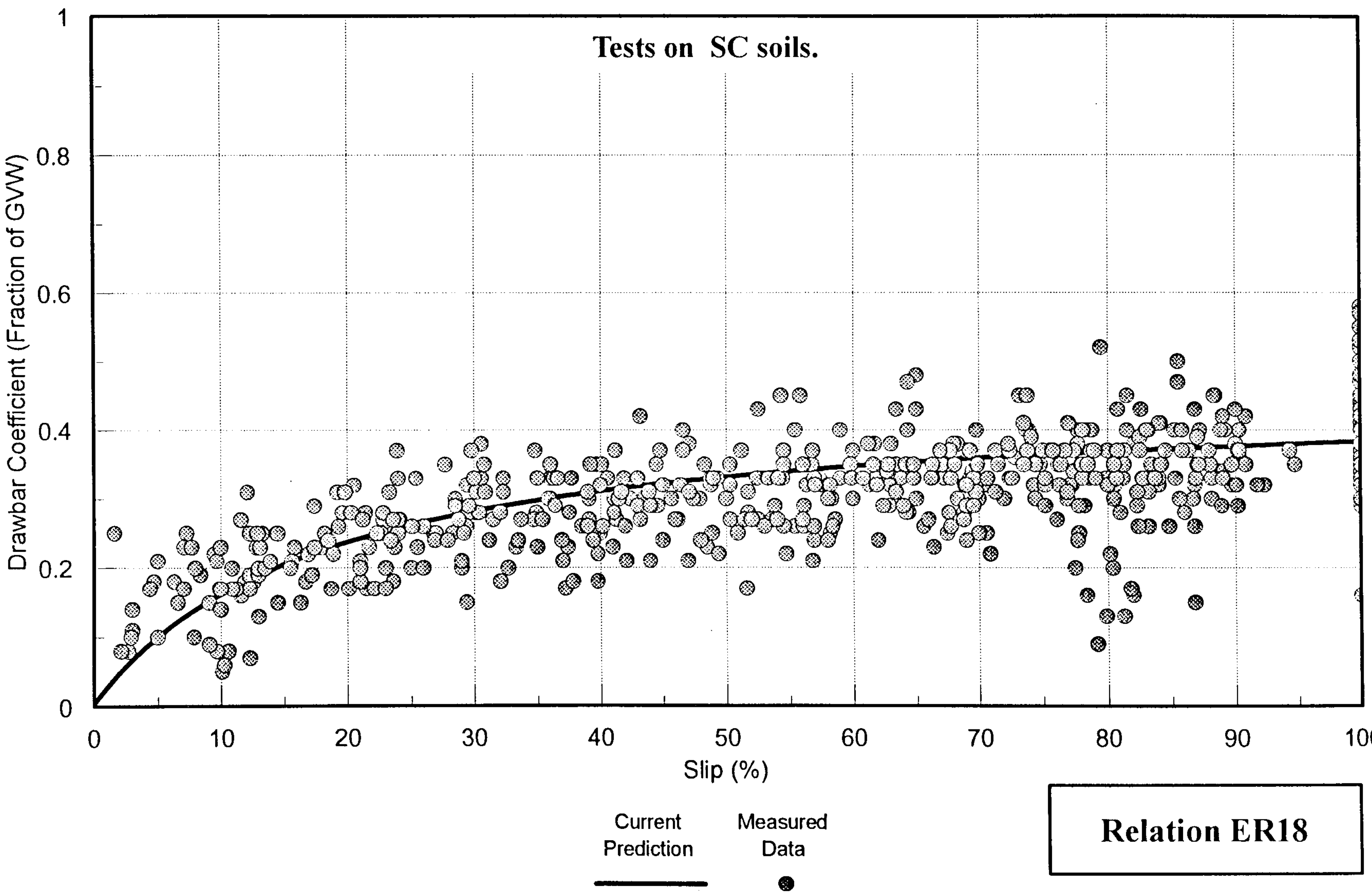
Slippery "Wet" Surfaces at "Maximum" Soil Strength

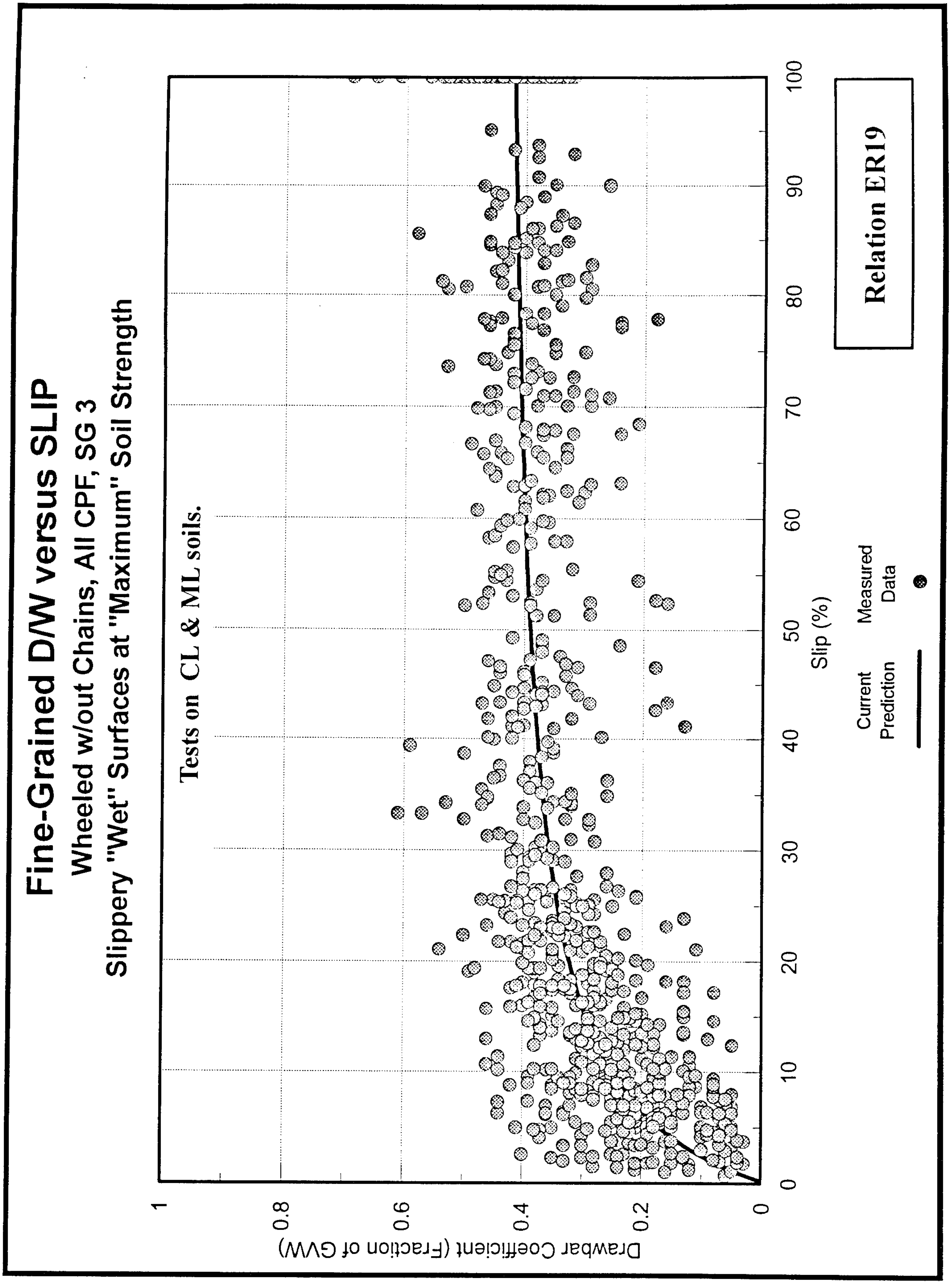


Fine-Grained D/W versus SLIP

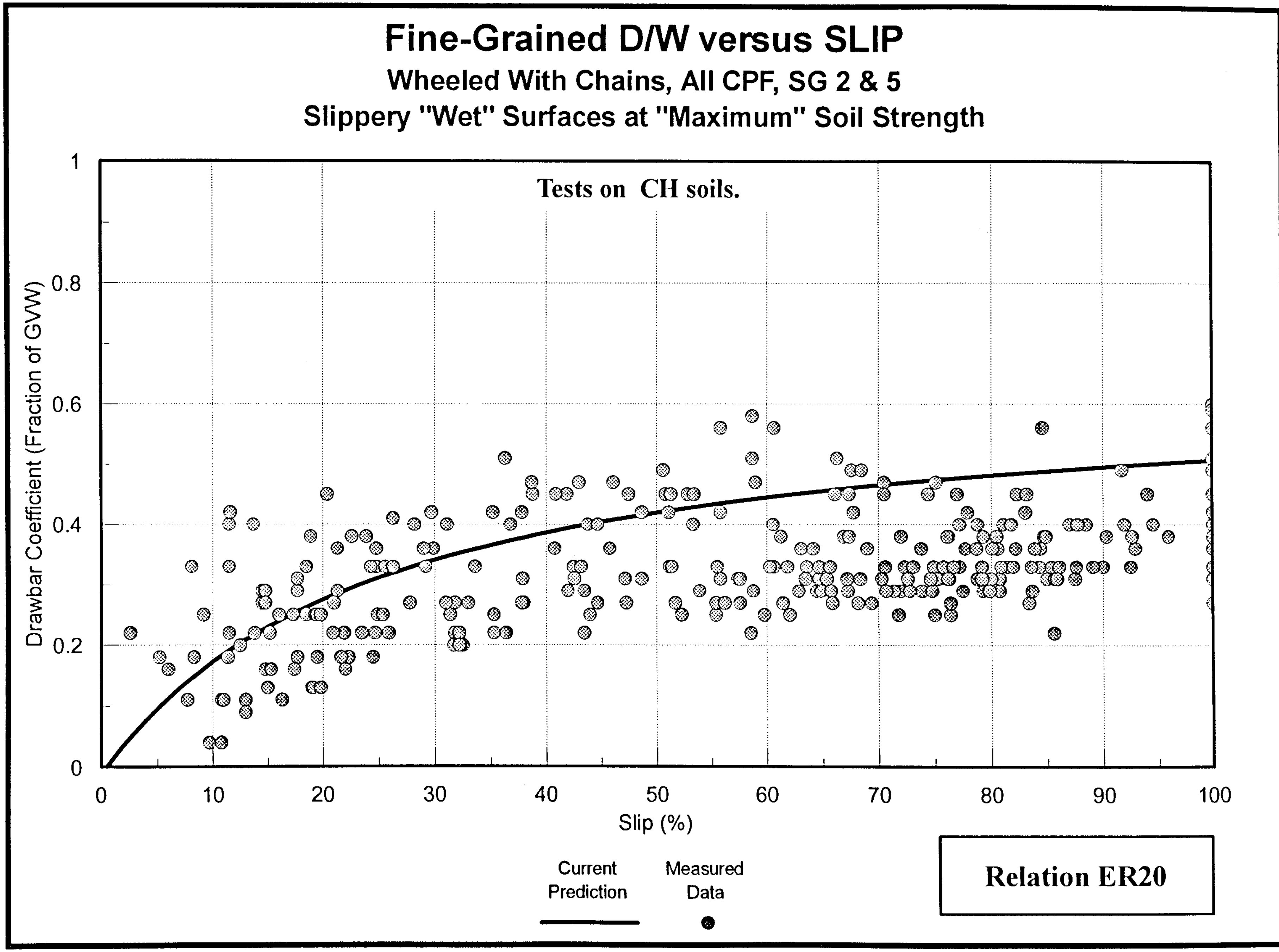
Wheeled w/out Chains, All CPF, SG 1

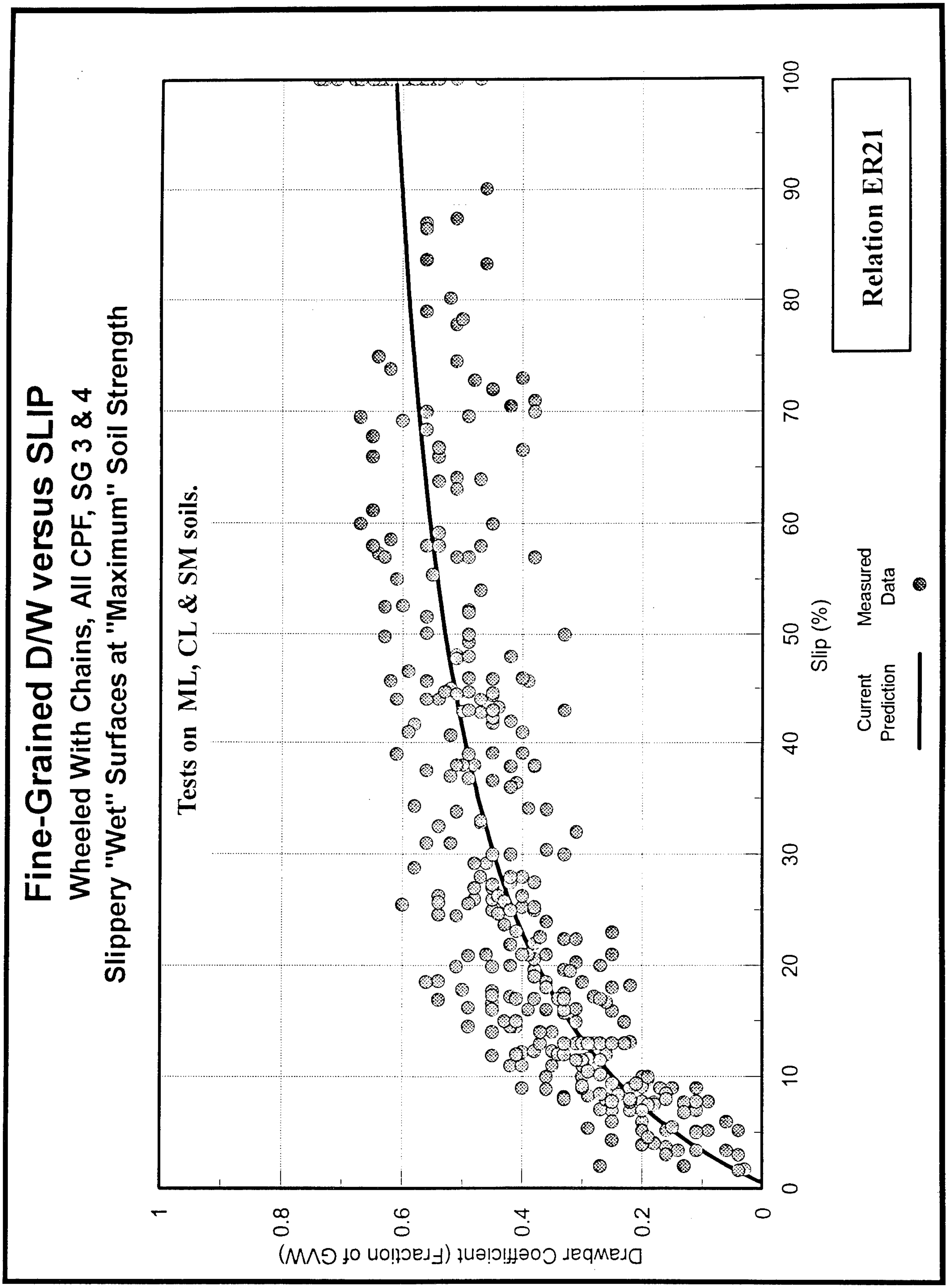
Slippery "Wet" Surfaces at "Maximum" Soil Strength



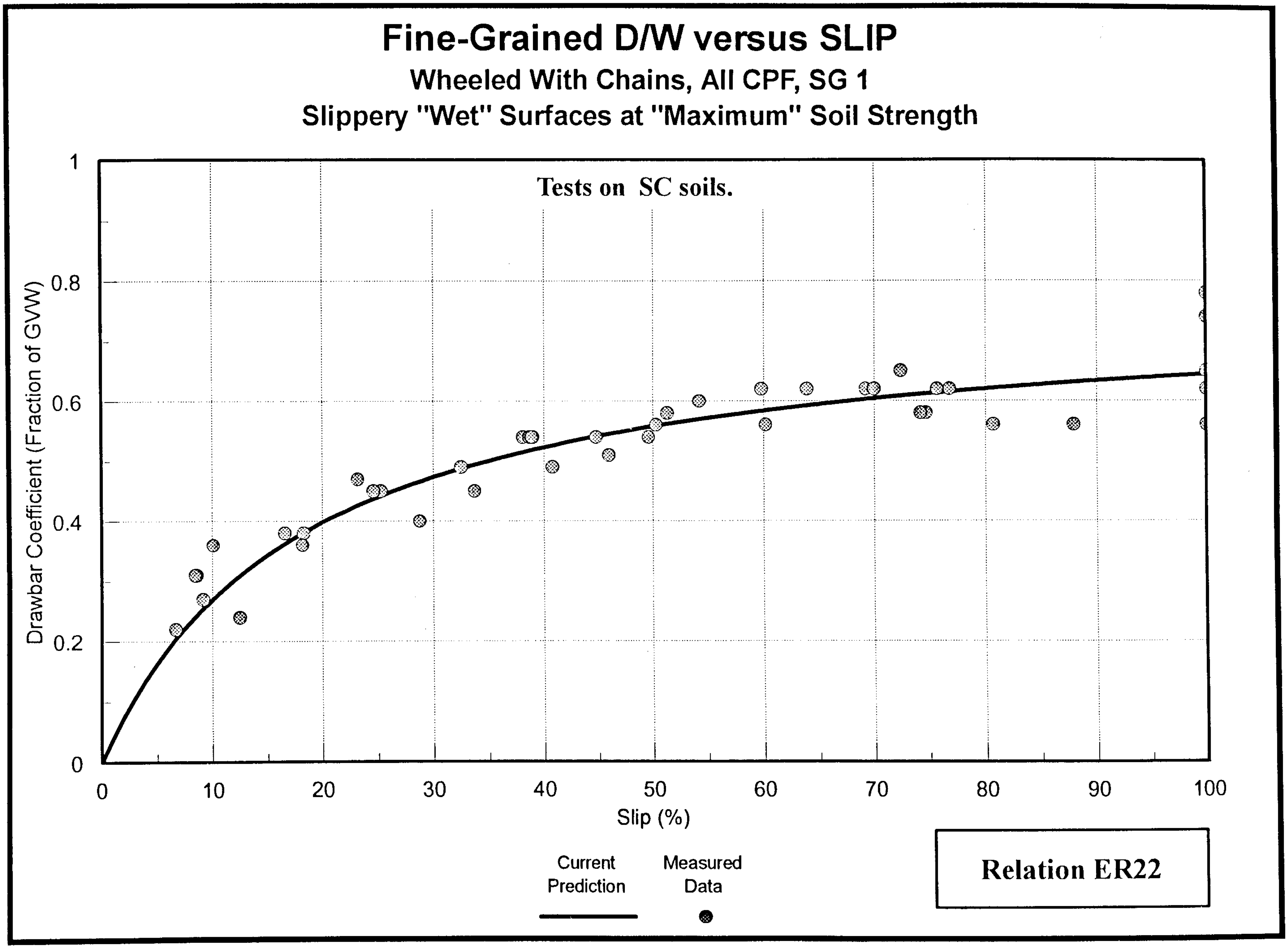


Fine-Grained D/W versus SLIP
Wheeled w/out Chains, All CPF, SG 3
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CL & ML soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER19

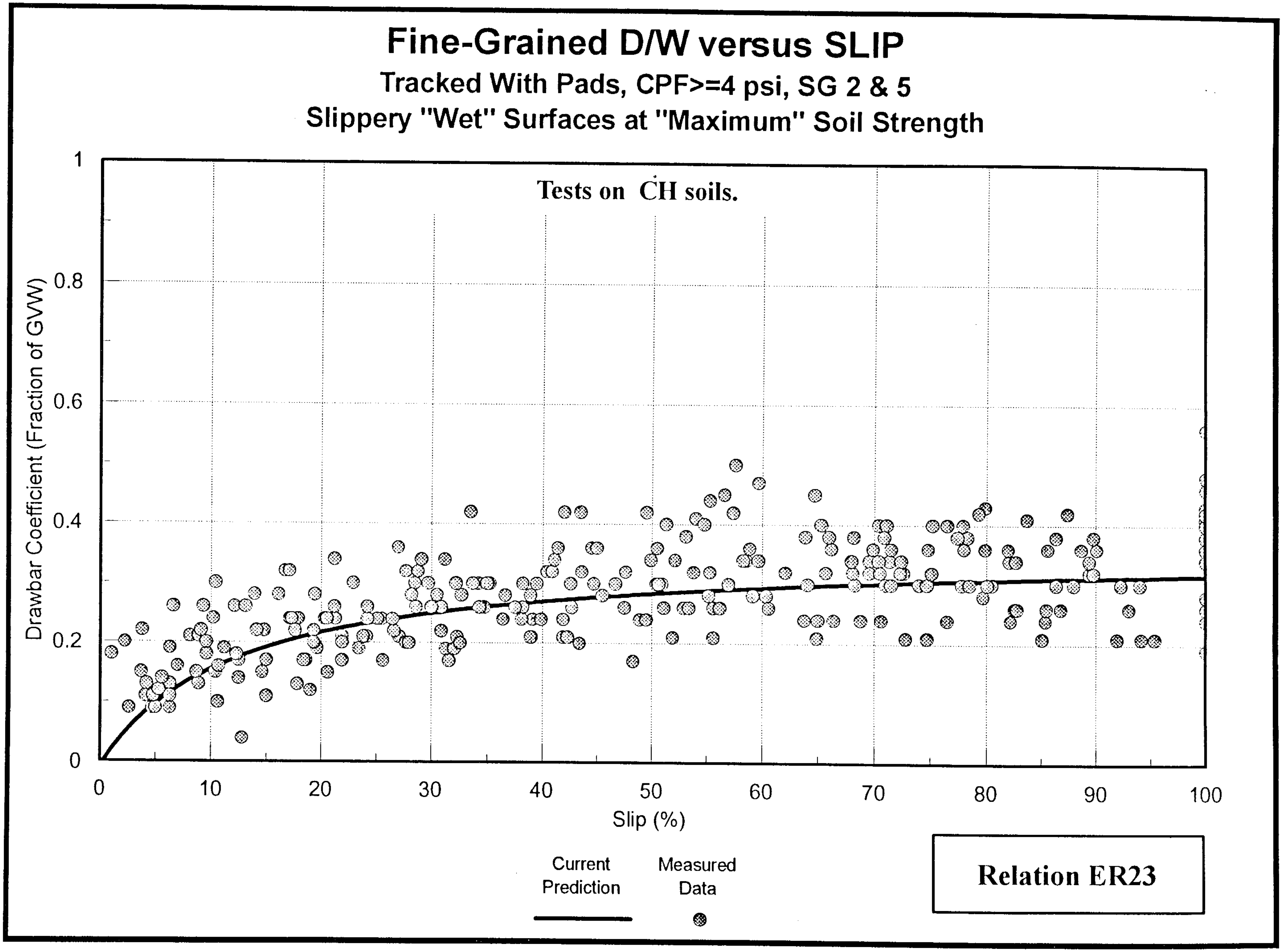

Fine-Grained D/W versus SLIP
Wheeled With Chains, All CPF, SG 2 & 5
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CH soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER20



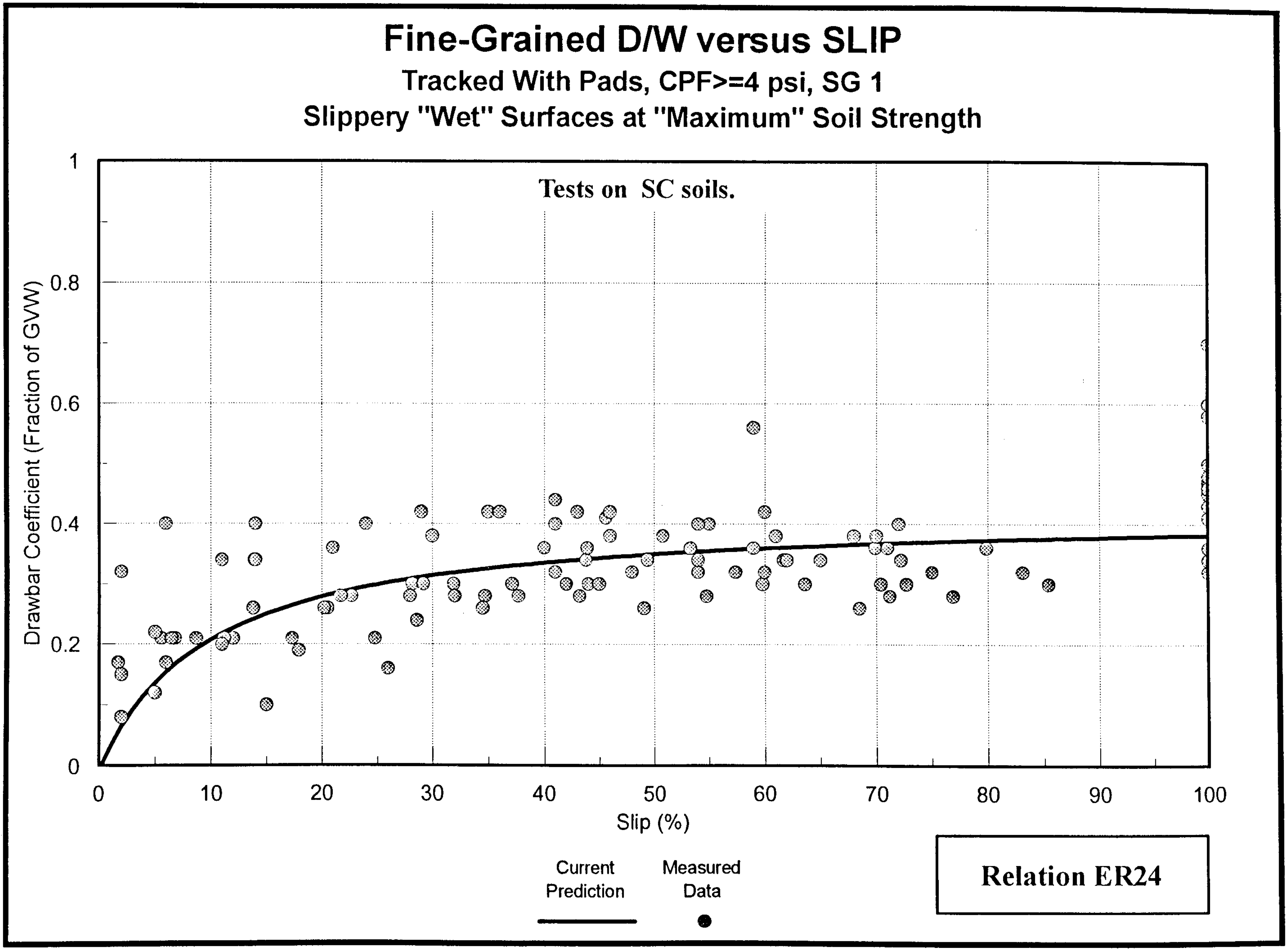
Fine-Grained D/W versus SLIP
Wheeled With Chains, All CPF, SG 3 & 4
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on ML, CL & SM soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER21



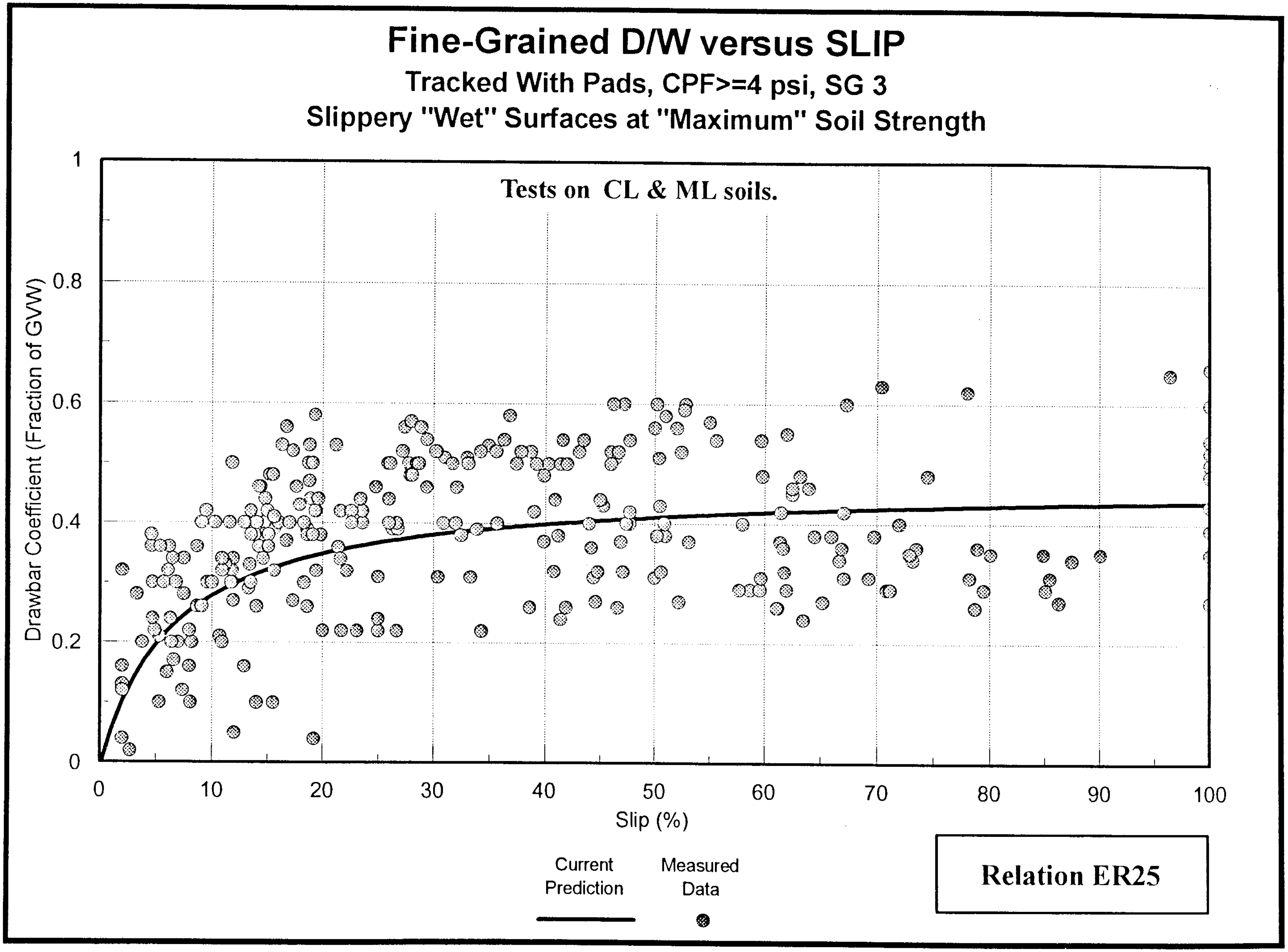
Fine-Grained D/W versus SLIP
Wheeled With Chains, All CPF, SG 1
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on SC soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER22

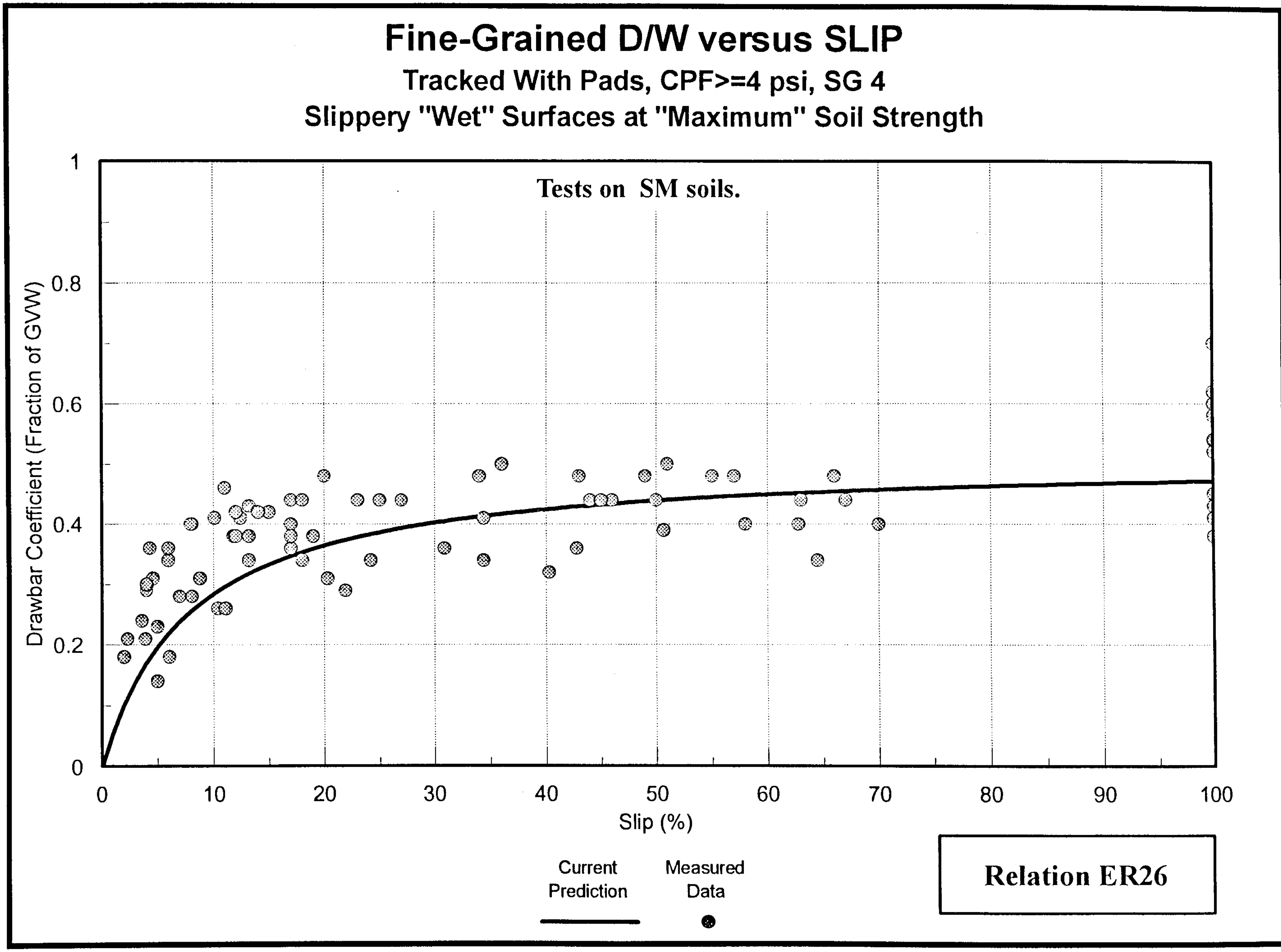


Fine-Grained D/W versus SLIP
Tracked With Pads, CPF>=4 psi, SG 2 & 5
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CH soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER23

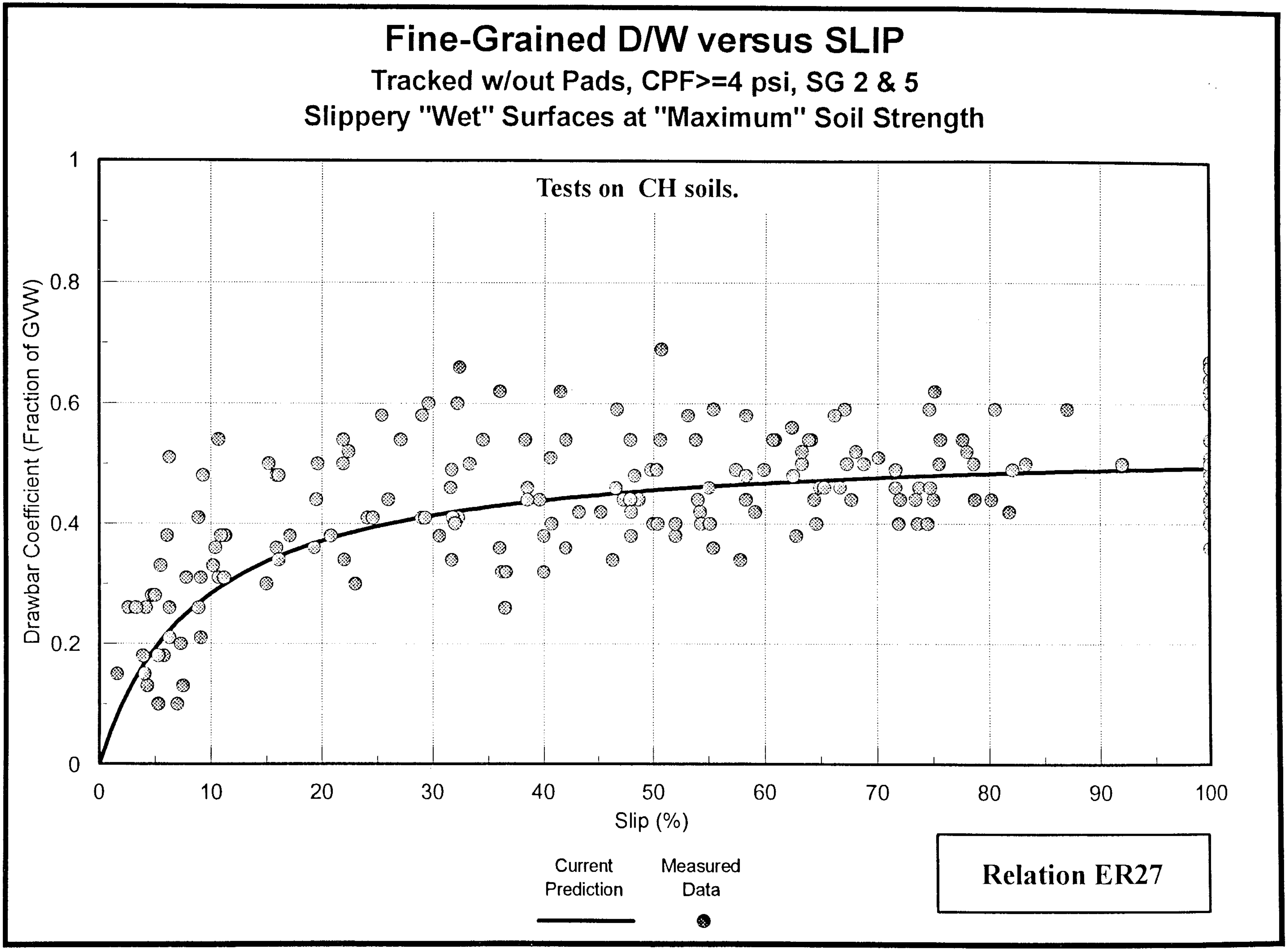


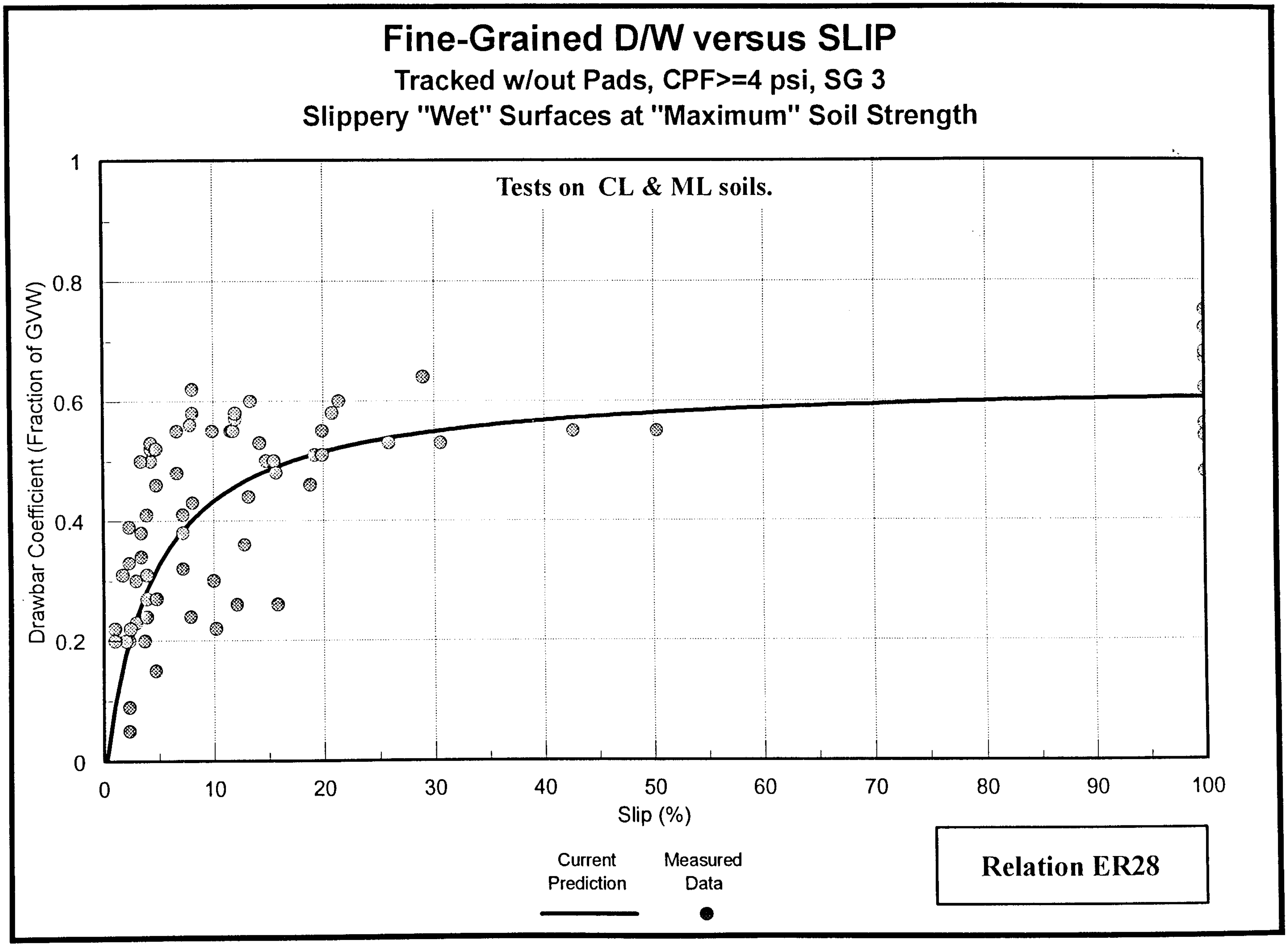
Fine-Grained D/W versus SLIP
Tracked With Pads, CPF>=4 psi, SG 1
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on SC soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER24


Fine-Grained D/W versus SLIP
Tracked With Pads, CPF>=4 psi, SG 3
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CL & ML soils.
Drawbar Coefficient (Fraction of GVW)
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER25

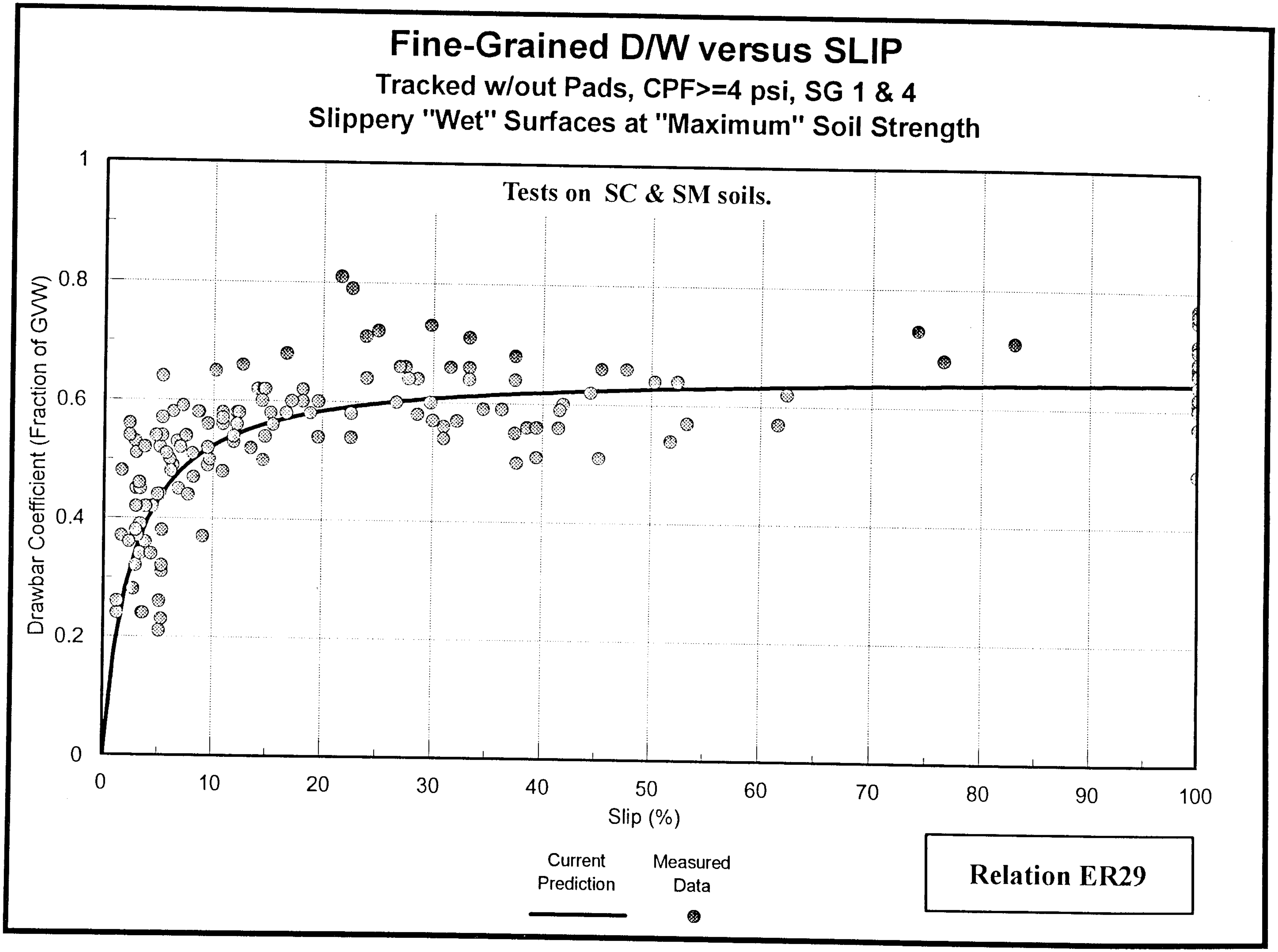


Fine-Grained D/W versus SLIP
Tracked With Pads, CPF>=4 psi, SG 4
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on SM soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER26

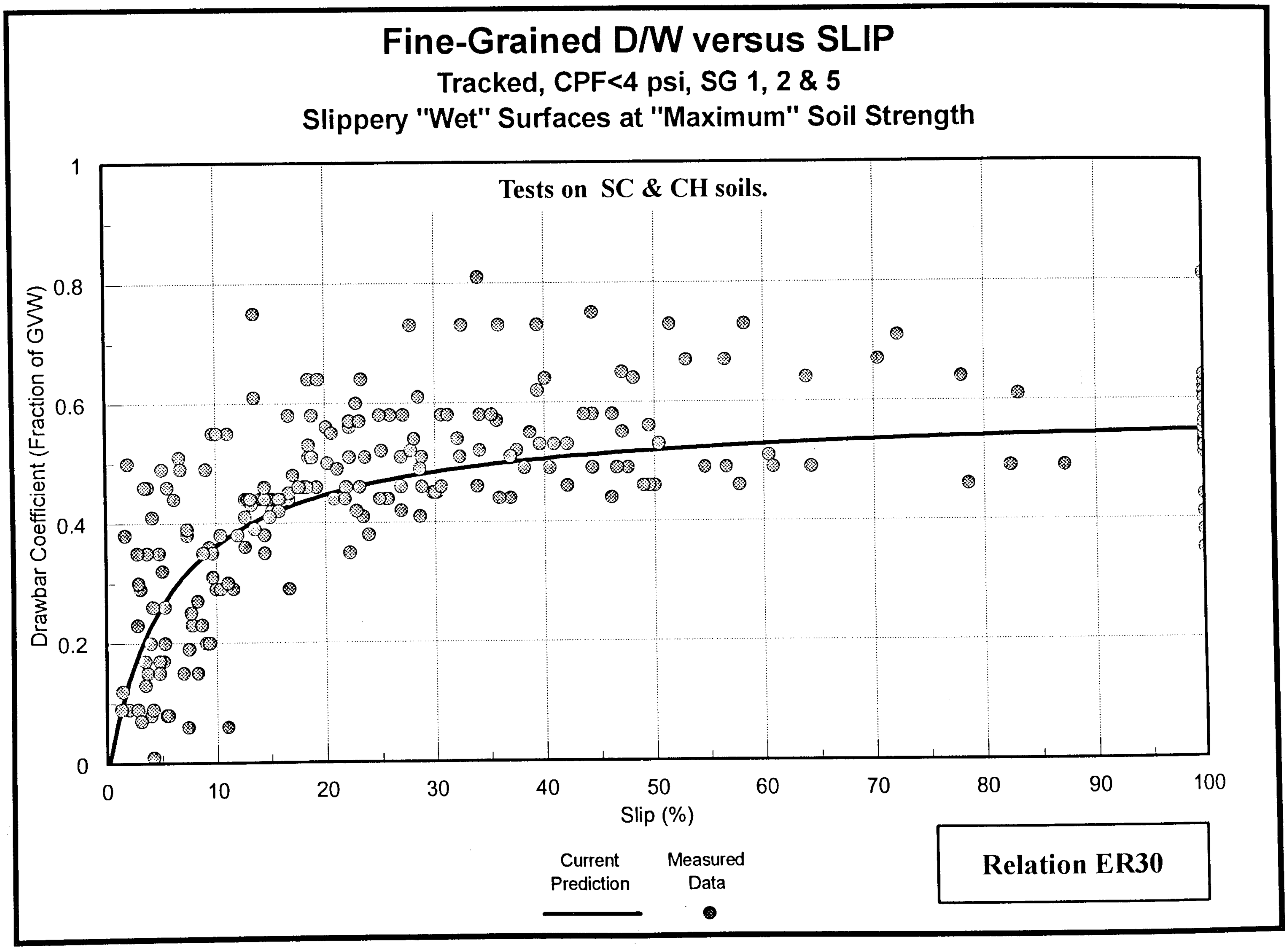

Fine-Grained D/W versus SLIP
Tracked w/out Pads, CPF>=4 psi, SG 2 & 5
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CH soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER27



Fine-Grained D/W versus SLIP
Tracked w/out Pads, CPF>=4 psi, SG 3
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on CL & ML soils.
Drawbar Coefficient (Fraction of GVW)
Slip (%)
Current Prediction
Measured Data
Relation ER28



Fine-Grained D/W versus SLIP
Tracked w/out Pads, CPF>=4 psi, SG 1 & 4
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on SC & SM soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER29



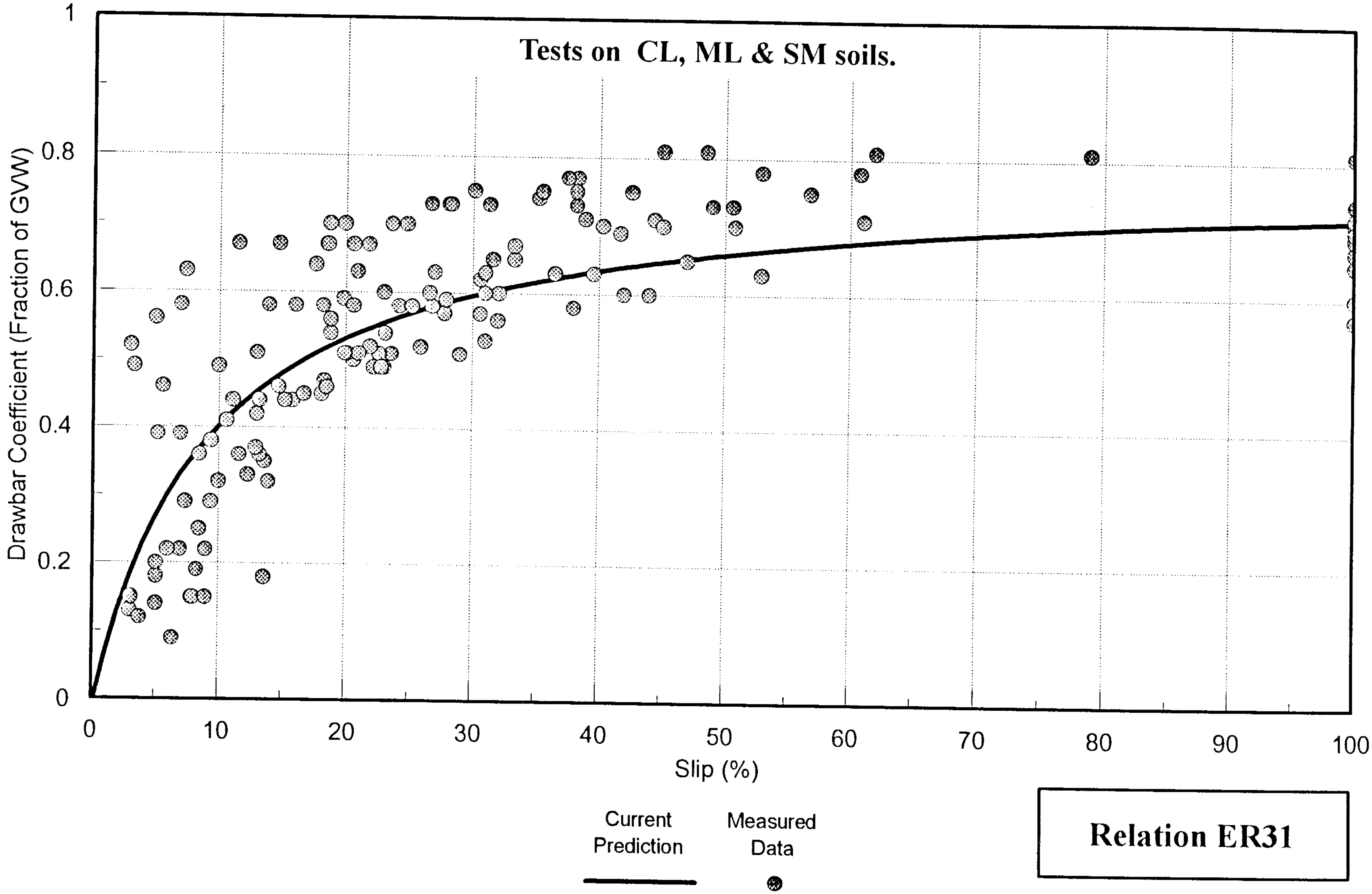
Fine-Grained D/W versus SLIP
Tracked, CPF<4 psi, SG 1, 2 & 5
Slippery "Wet" Surfaces at "Maximum" Soil Strength
Tests on SC & CH soils.
Drawbar Coefficient (Fraction of GVW)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Current Prediction
Measured Data
Relation ER30

Plate 42

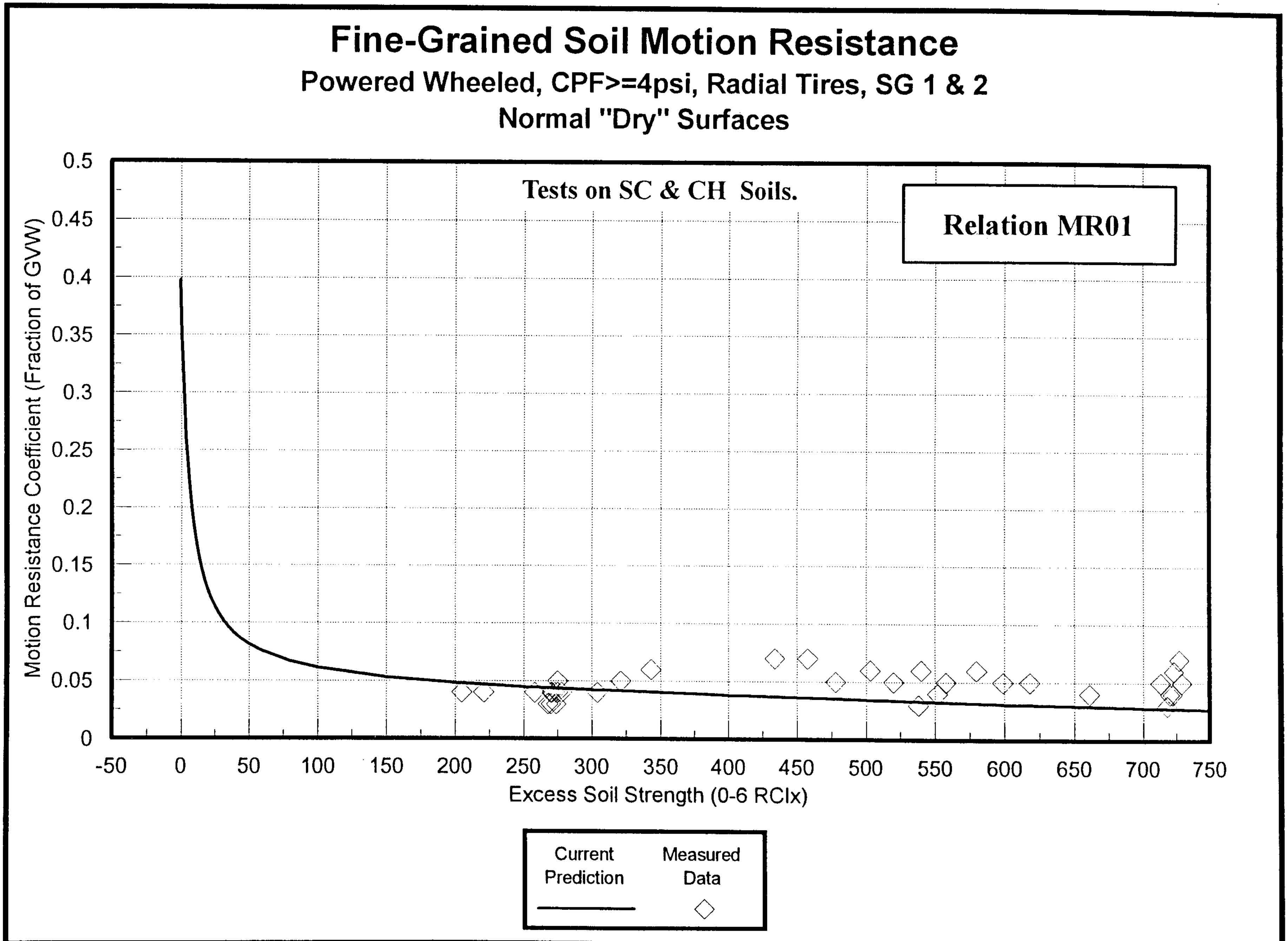
Fine-Grained D/W versus SLIP

Tracked, CPF<4 psi, SG 3 & 4

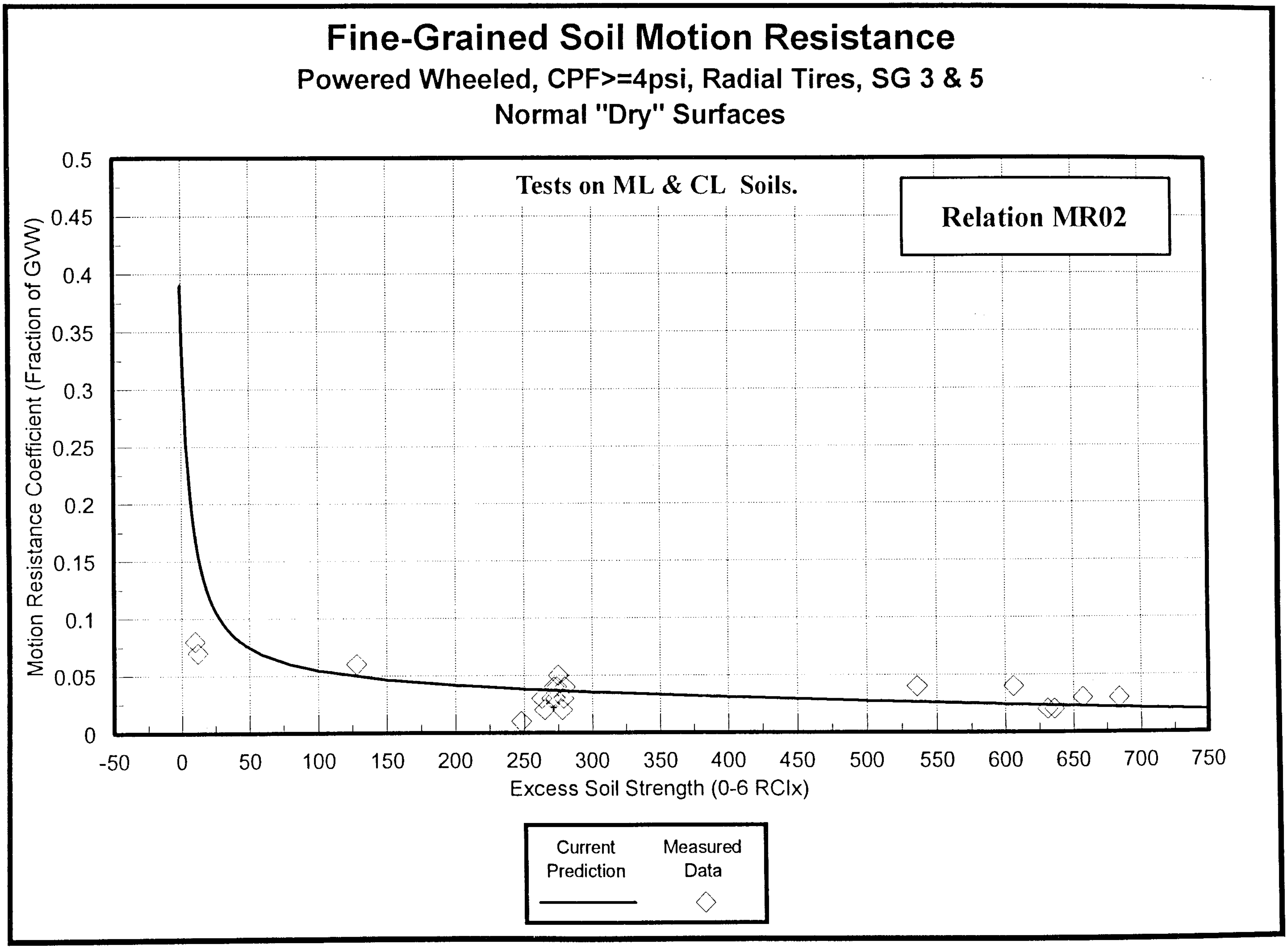
Slippery "Wet" Surfaces at "Maximum" Soil Strength

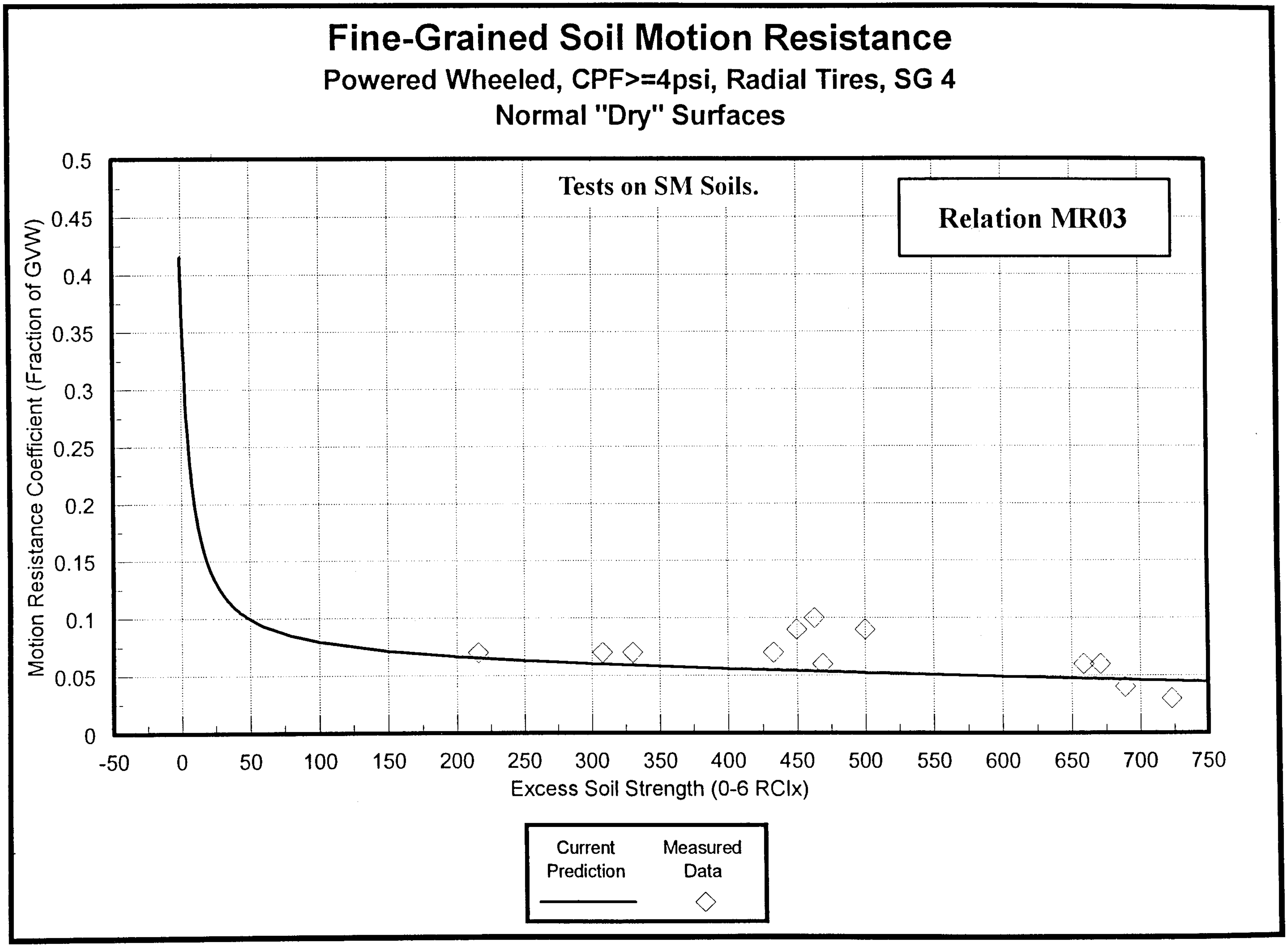


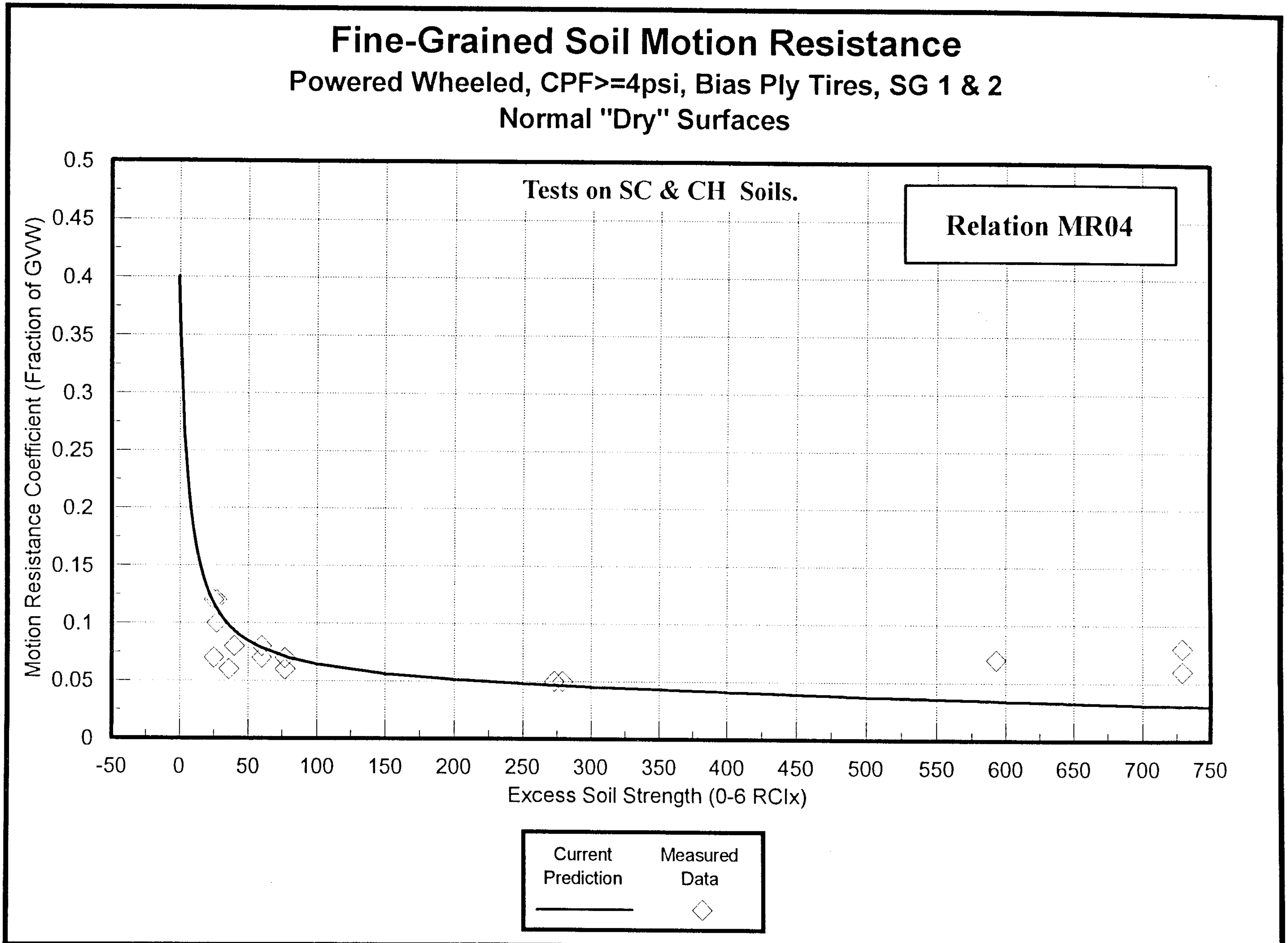
Relation ER31

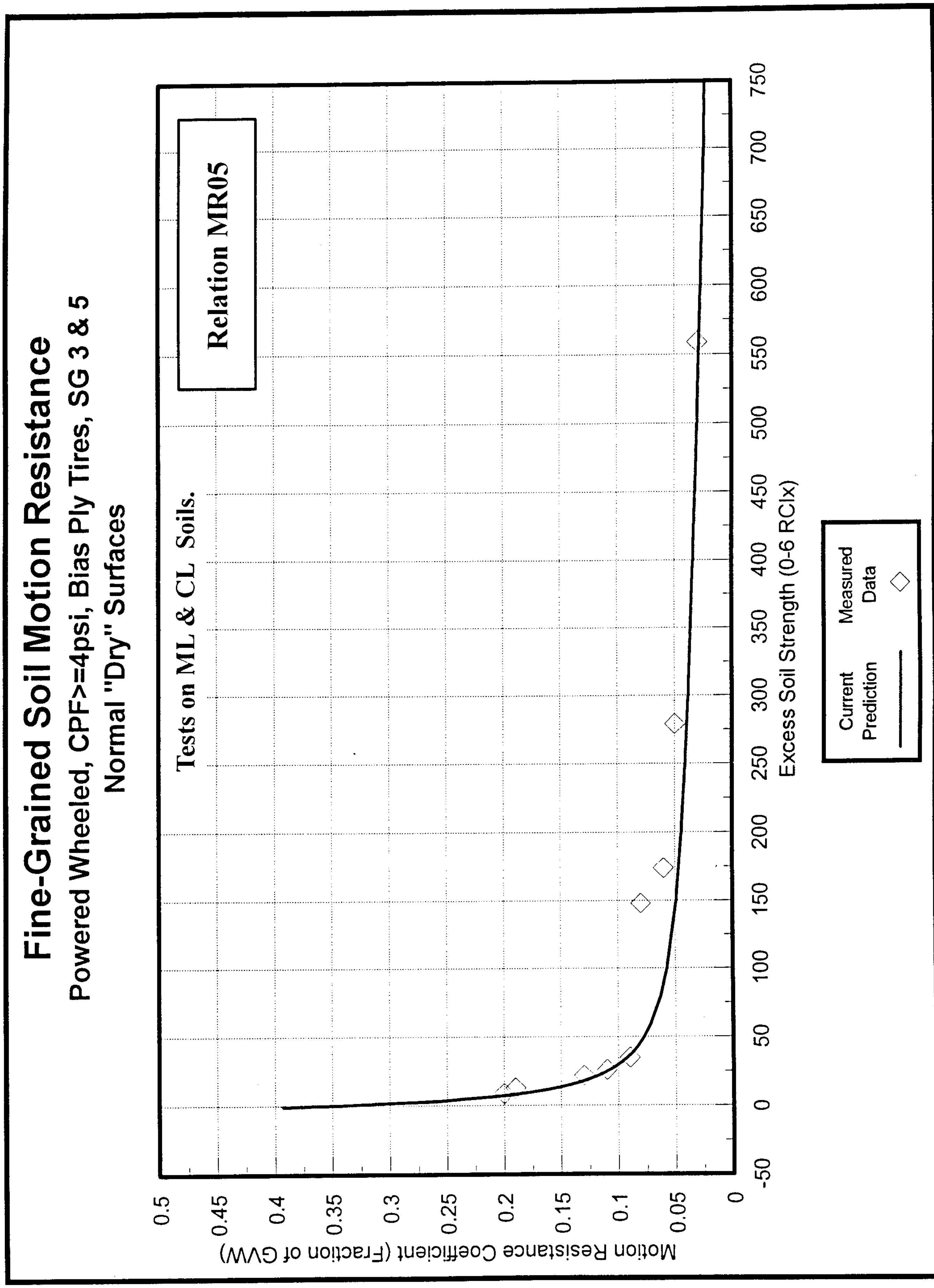


Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Radial Tires, SG 1 & 2
Normal "Dry" Surfaces
Tests on SC & CH Soils.
Relation MR01
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data


Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Radial Tires, SG 3 & 5
Normal "Dry" Surfaces
Tests on ML & CL Soils.
Relation MR02
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data


Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Radial Tires, SG 4
Normal "Dry" Surfaces
Tests on SM Soils.
Relation MR03
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data


Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 1 & 2
Normal "Dry" Surfaces
Tests on SC & CH Soils.
Relation MR04
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data

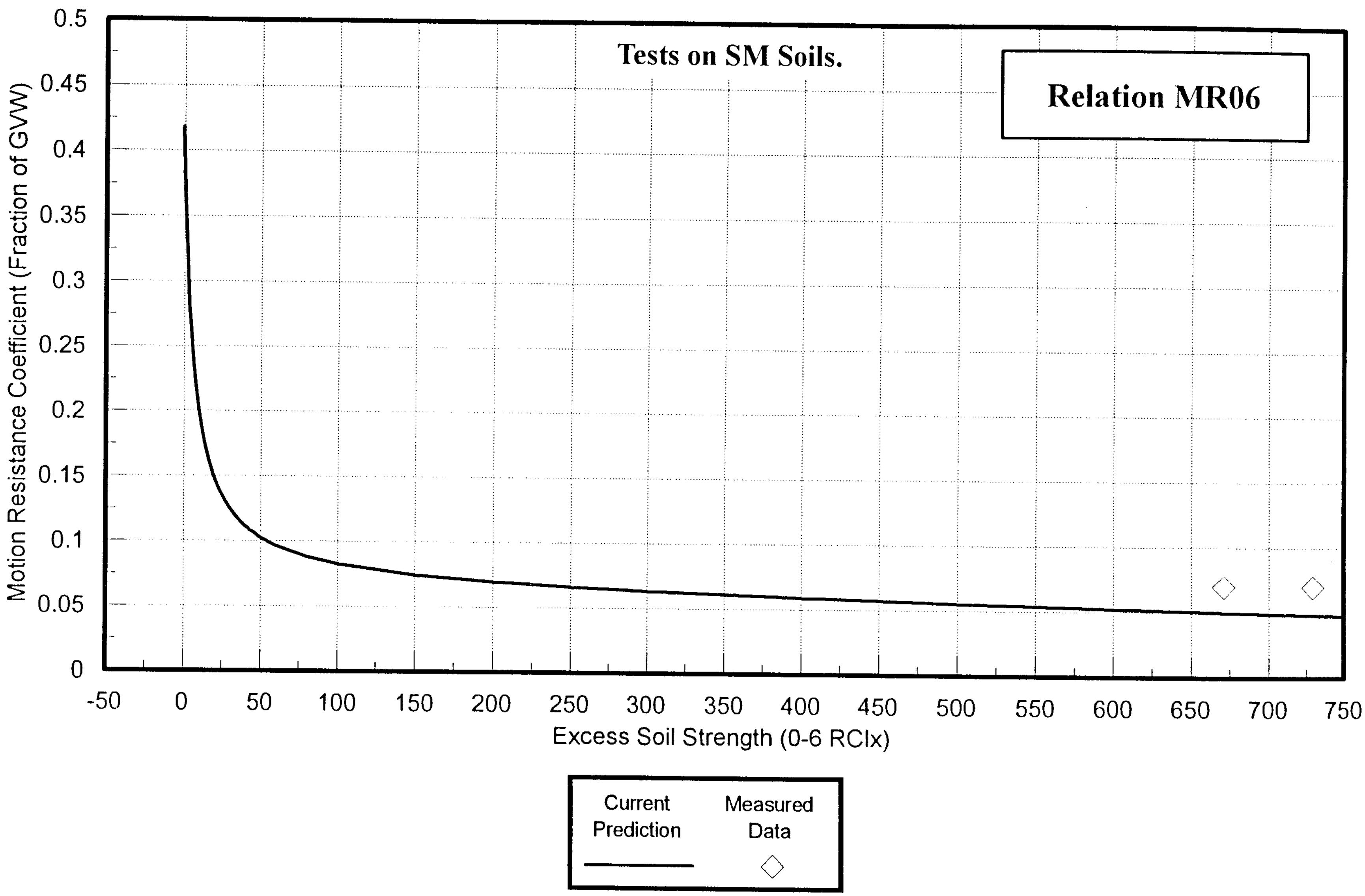


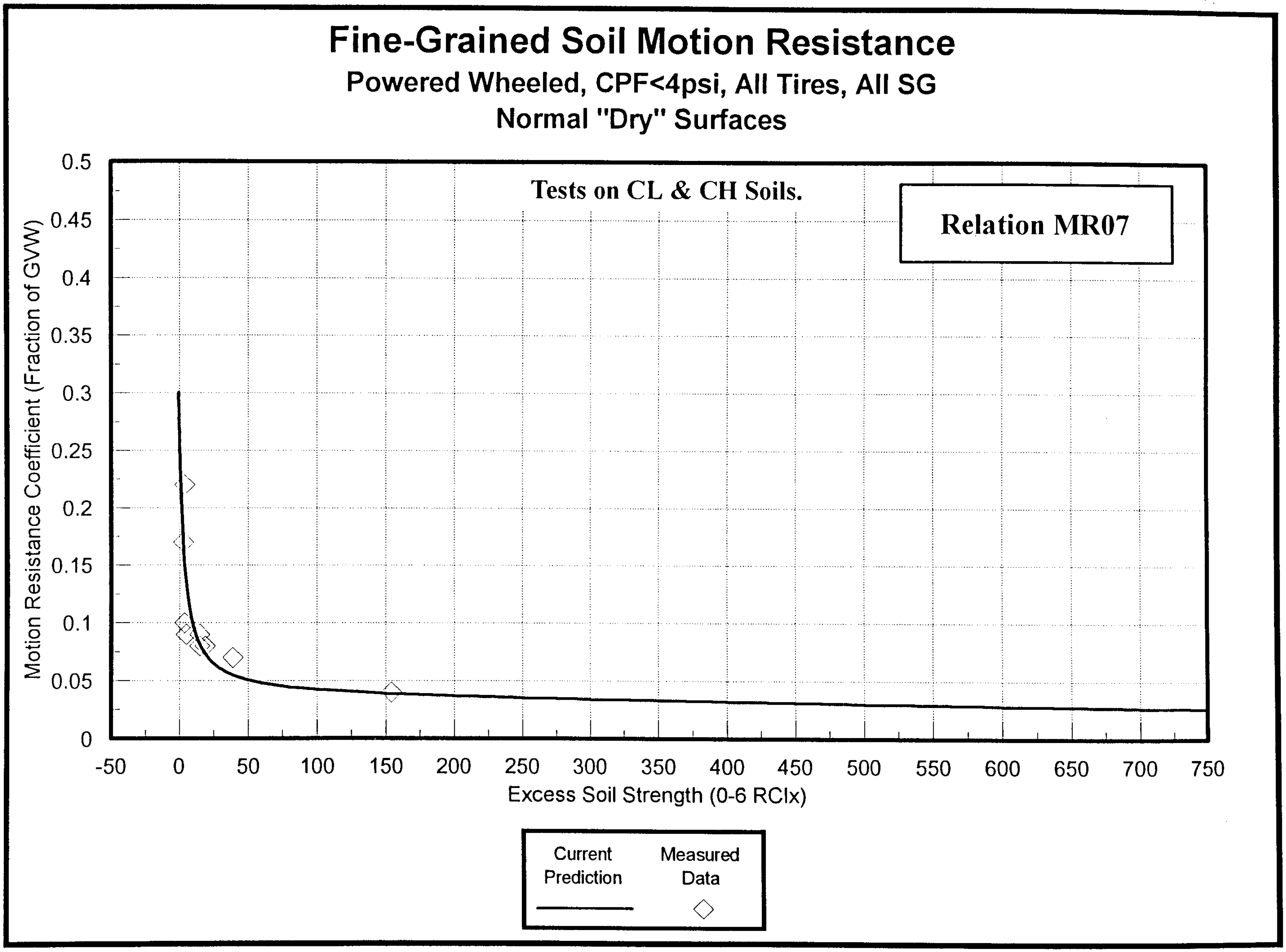
Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 3 & 5
Normal "Dry" Surfaces
Relation MR05
Tests on ML & CL Soils.
Motion Resistance Coefficient (Fraction of GVW)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data

Fine-Grained Soil Motion Resistance

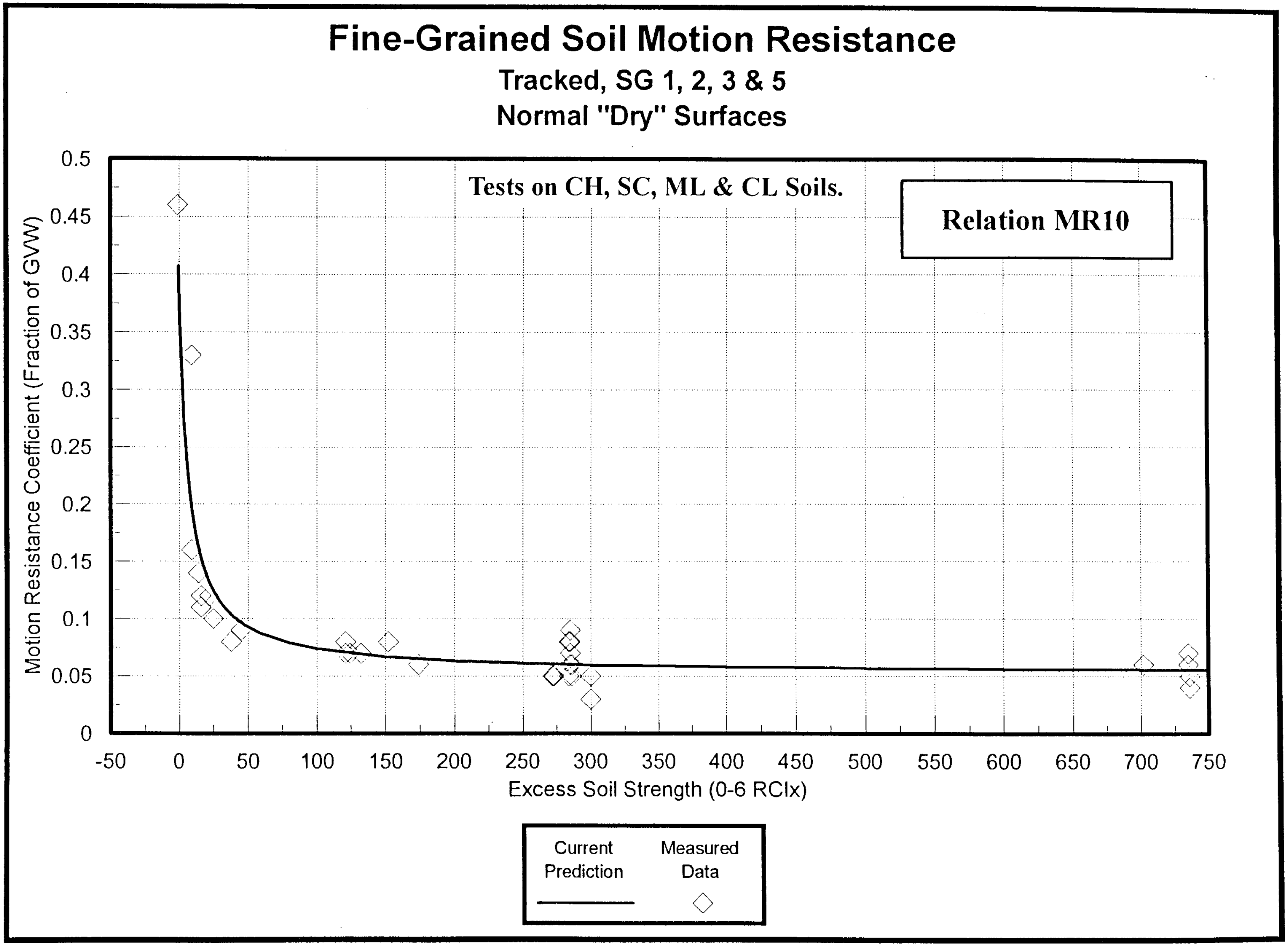
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 4

Normal "Dry" Surfaces

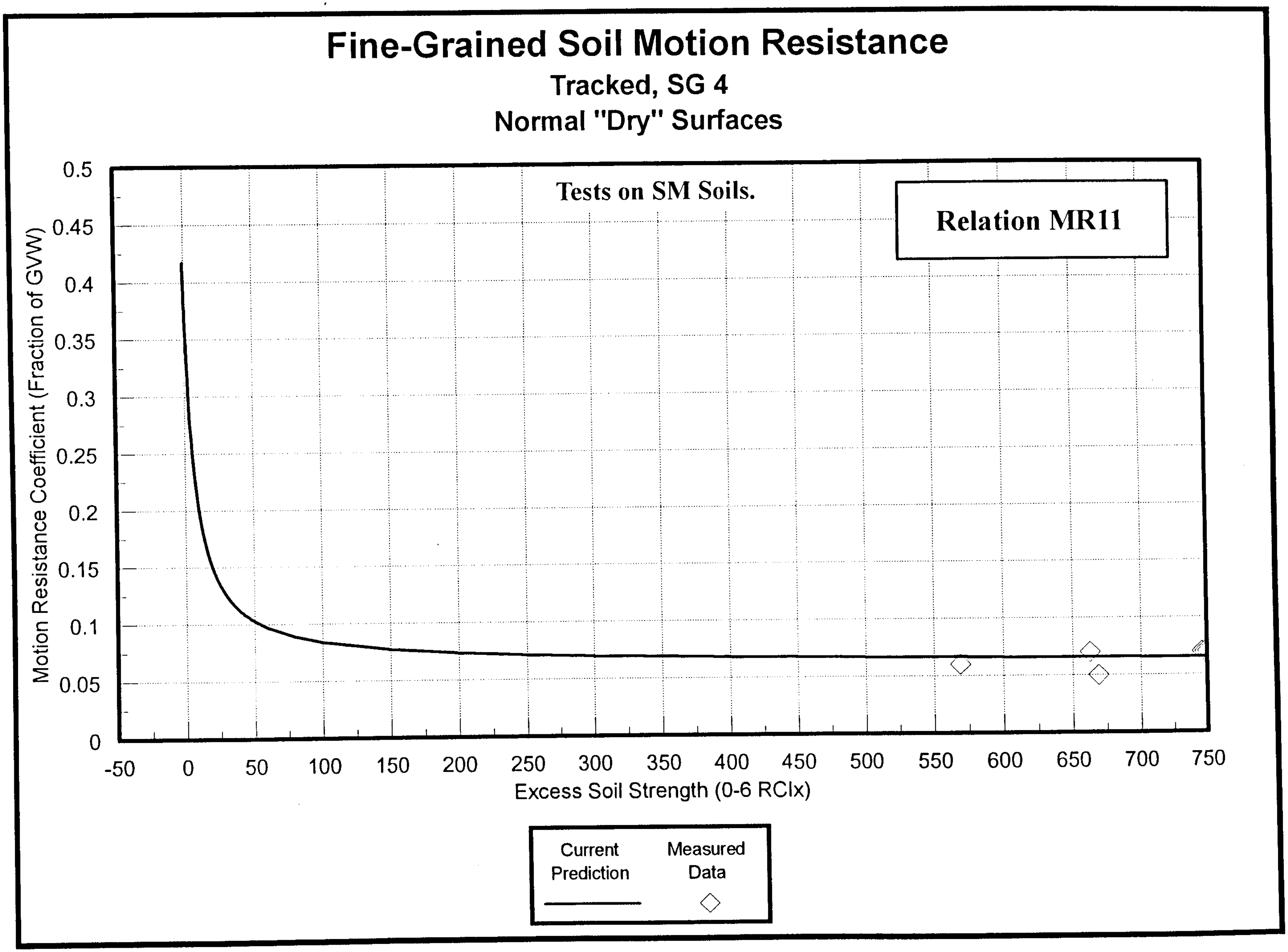


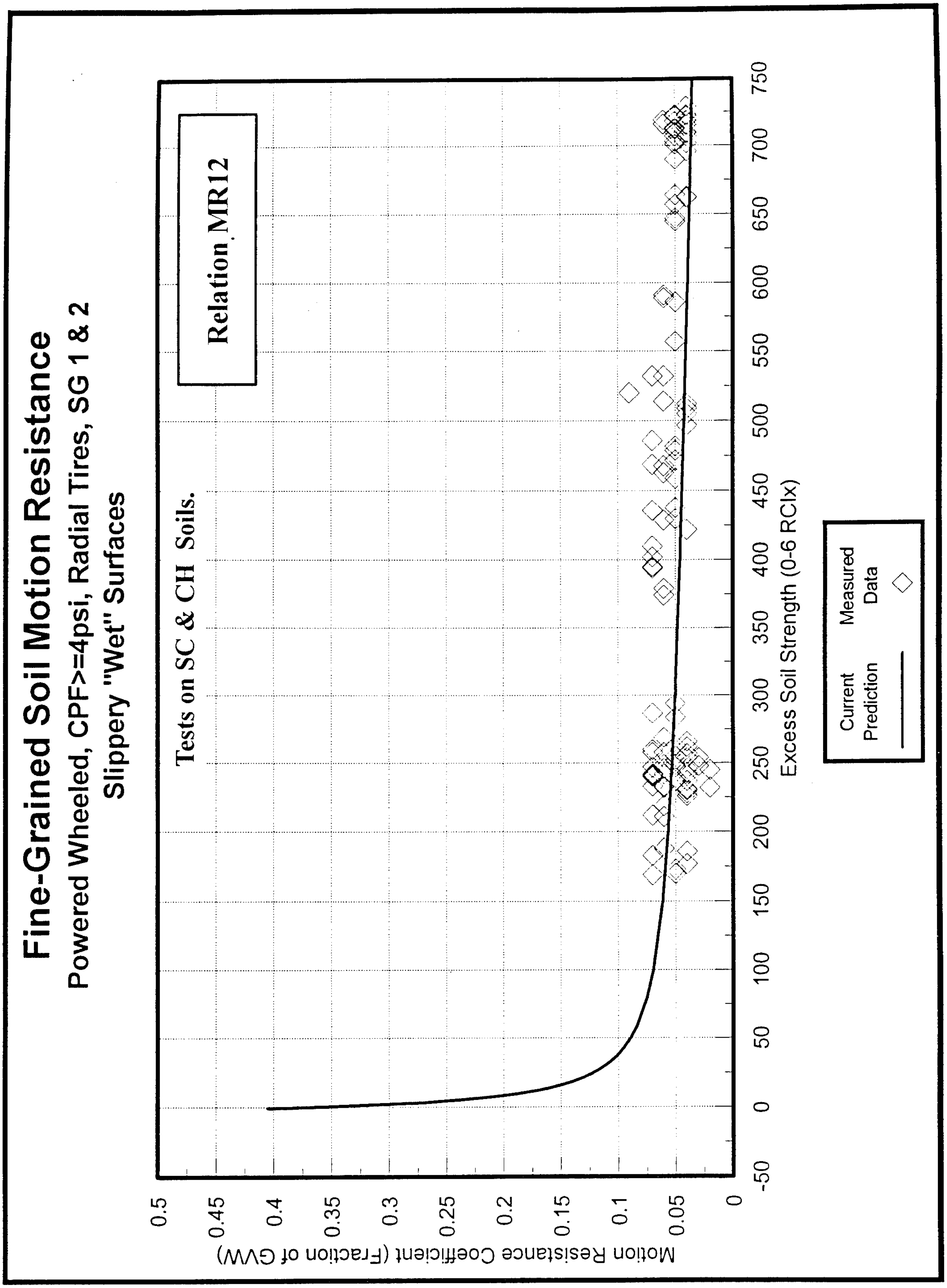


Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF<4psi, All Tires, All SG
Normal "Dry" Surfaces
Tests on CL & CH Soils.
Relation MR07
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data



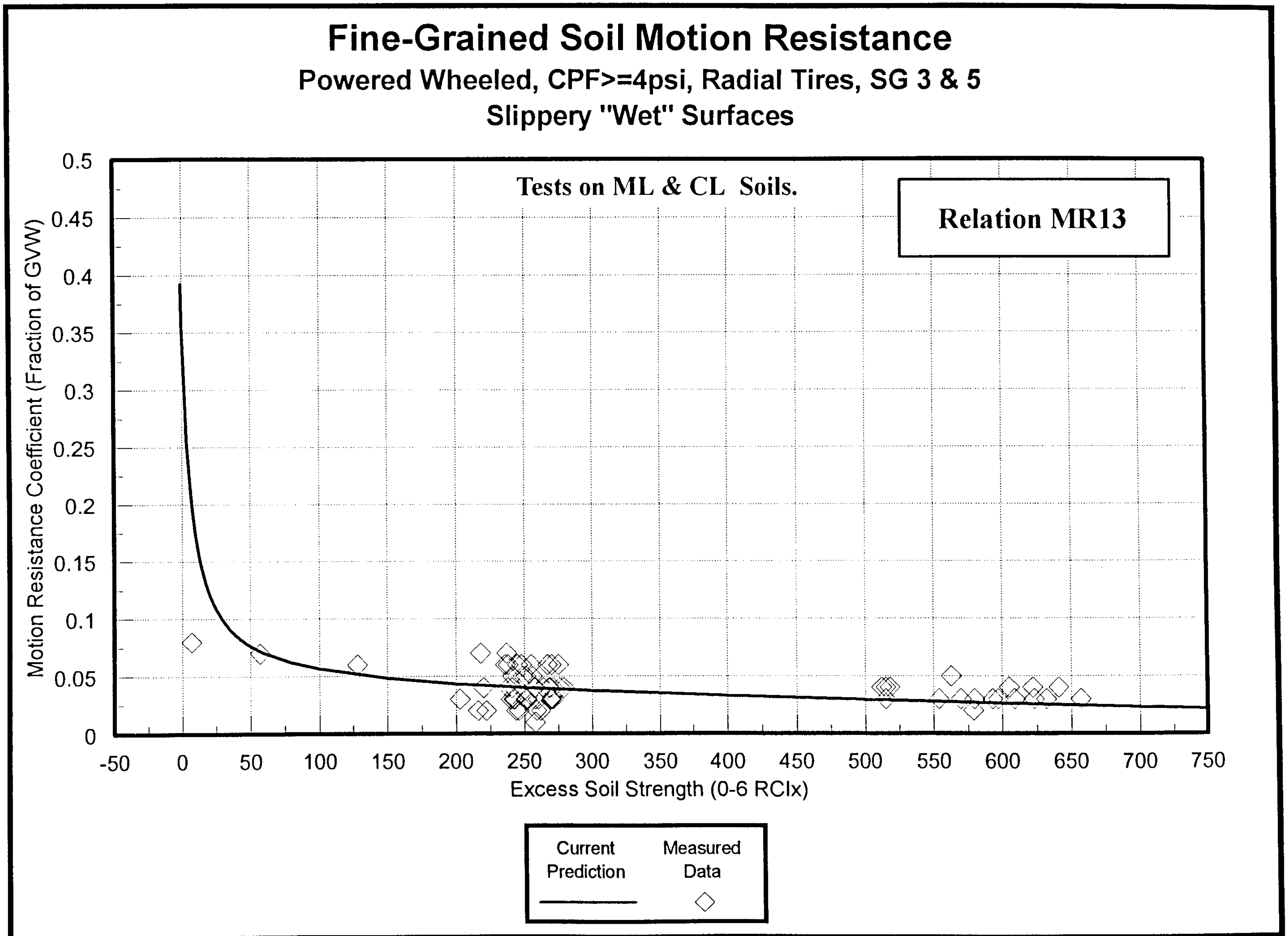
Fine-Grained Soil Motion Resistance
Tracked, SG 1, 2, 3 & 5
Normal "Dry" Surfaces
Tests on CH, SC, ML & CL Soils.
Relation MR10
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data


Fine-Grained Soil Motion Resistance
Tracked, SG 4
Normal "Dry" Surfaces
Tests on SM Soils.
Relation MR11
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data



Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Radial Tires, SG 1 & 2
Slippery "Wet" Surfaces
Tests on SC & CH Soils.
Relation MR12
Motion Resistance Coefficient (Fraction of GVW)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Excess Soil Strength (0-6 RCIx)
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Current Prediction
Measured Data

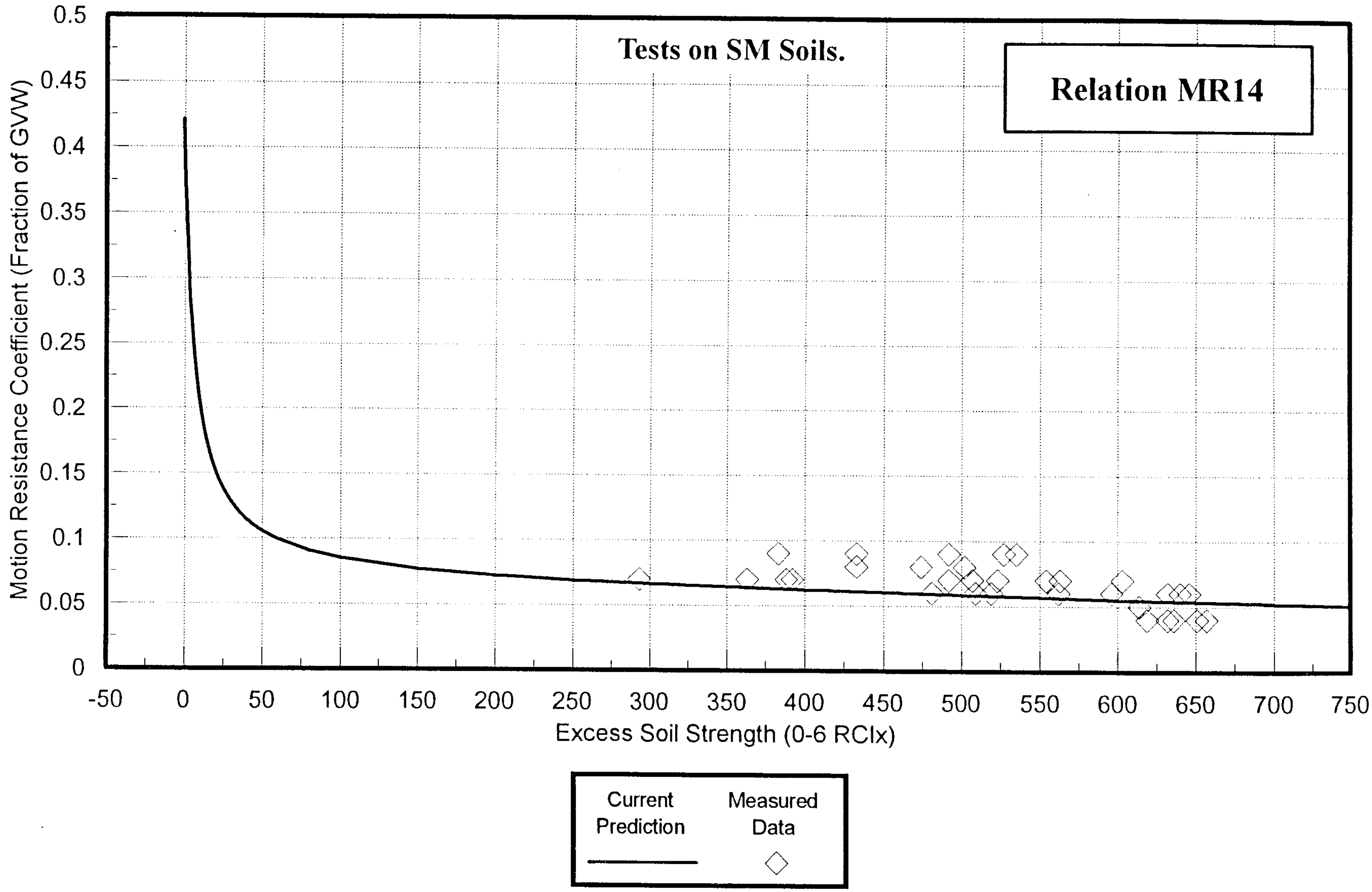
Plate 52

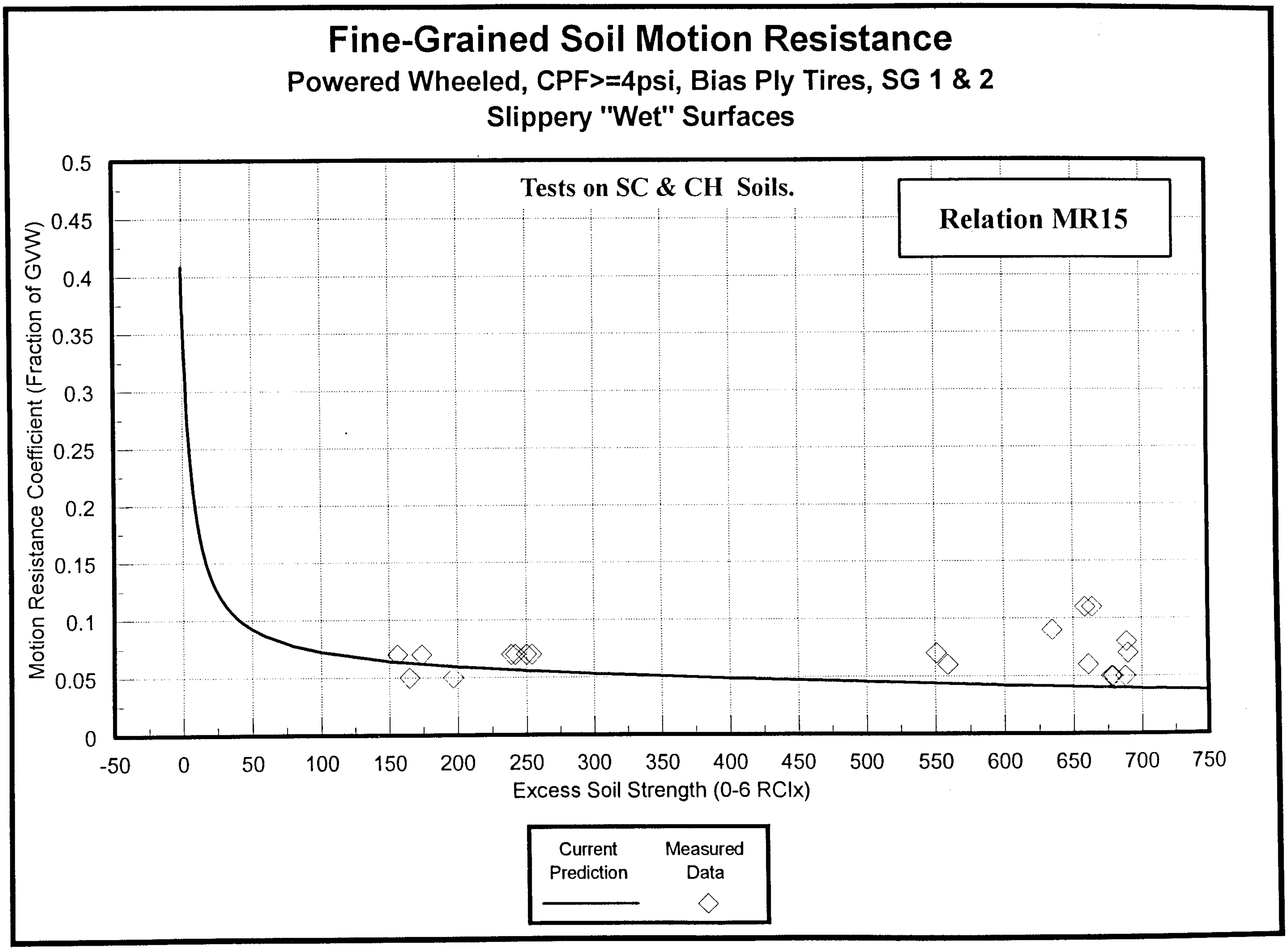

Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Radial Tires, SG 3 & 5
Slippery "Wet" Surfaces
Tests on ML & CL Soils.
Relation MR13
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data

Fine-Grained Soil Motion Resistance

Powered Wheeled, CPF>=4psi, Radial Tires, SG 4

Slippery "Wet" Surfaces

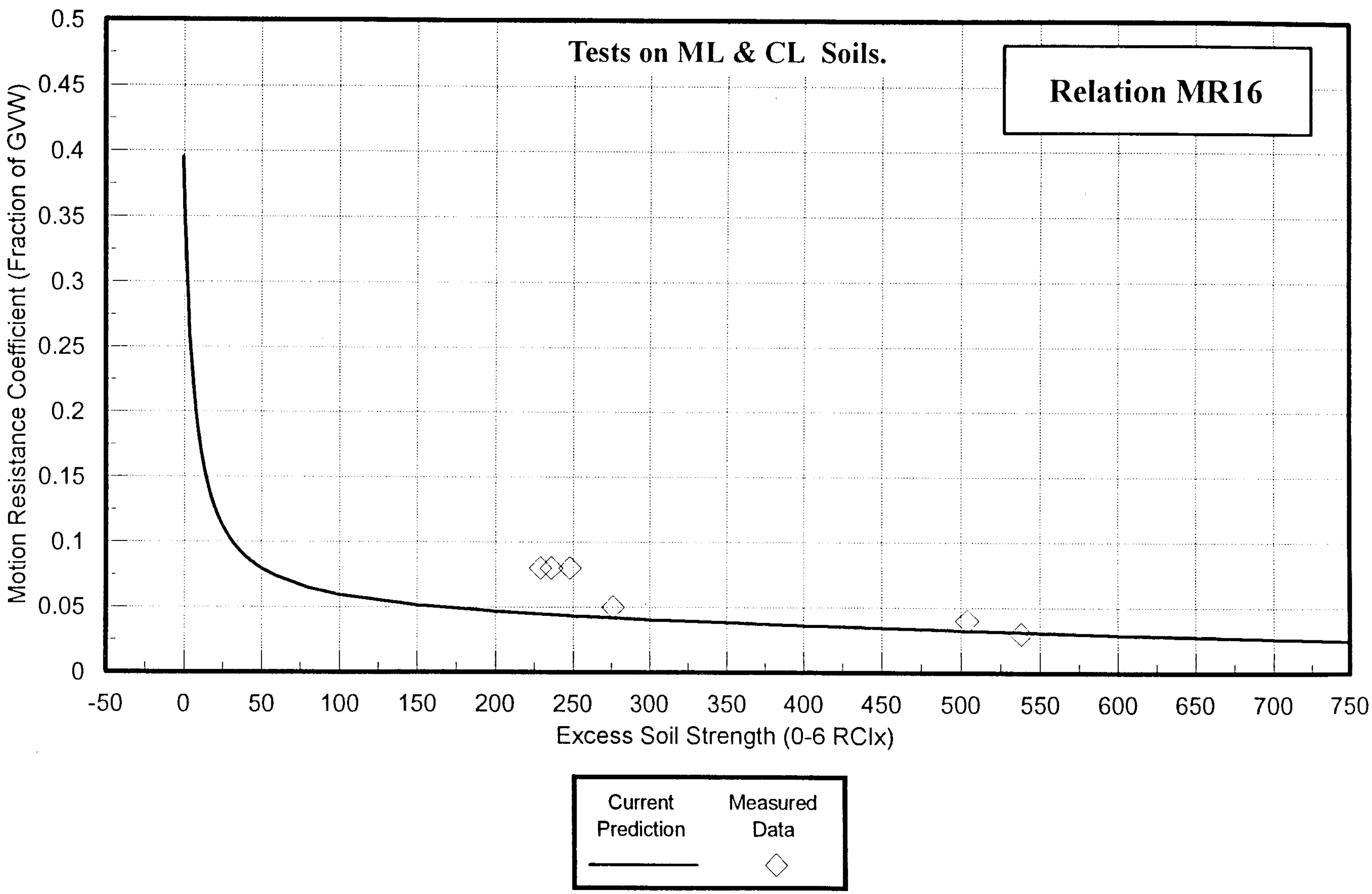


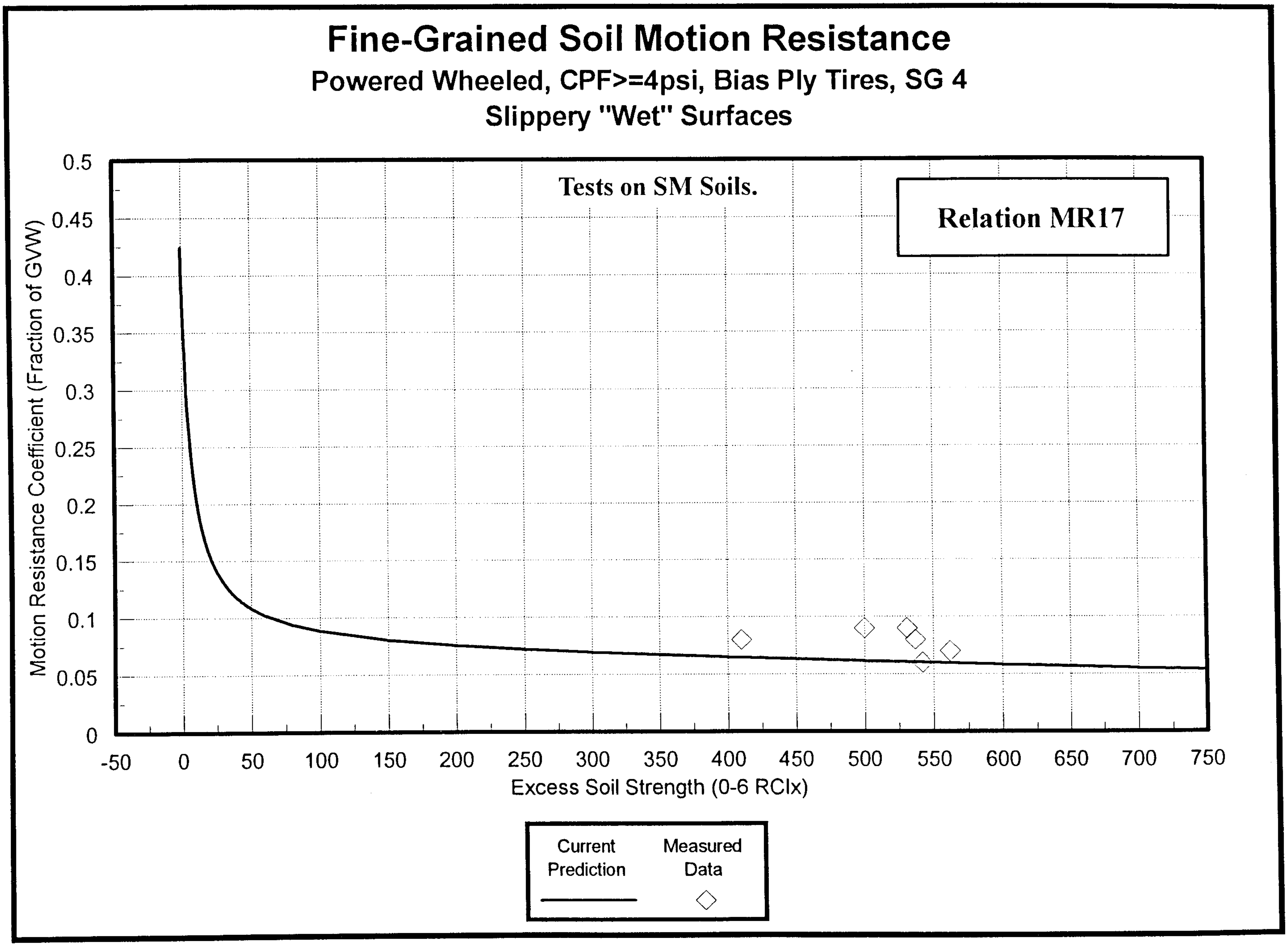


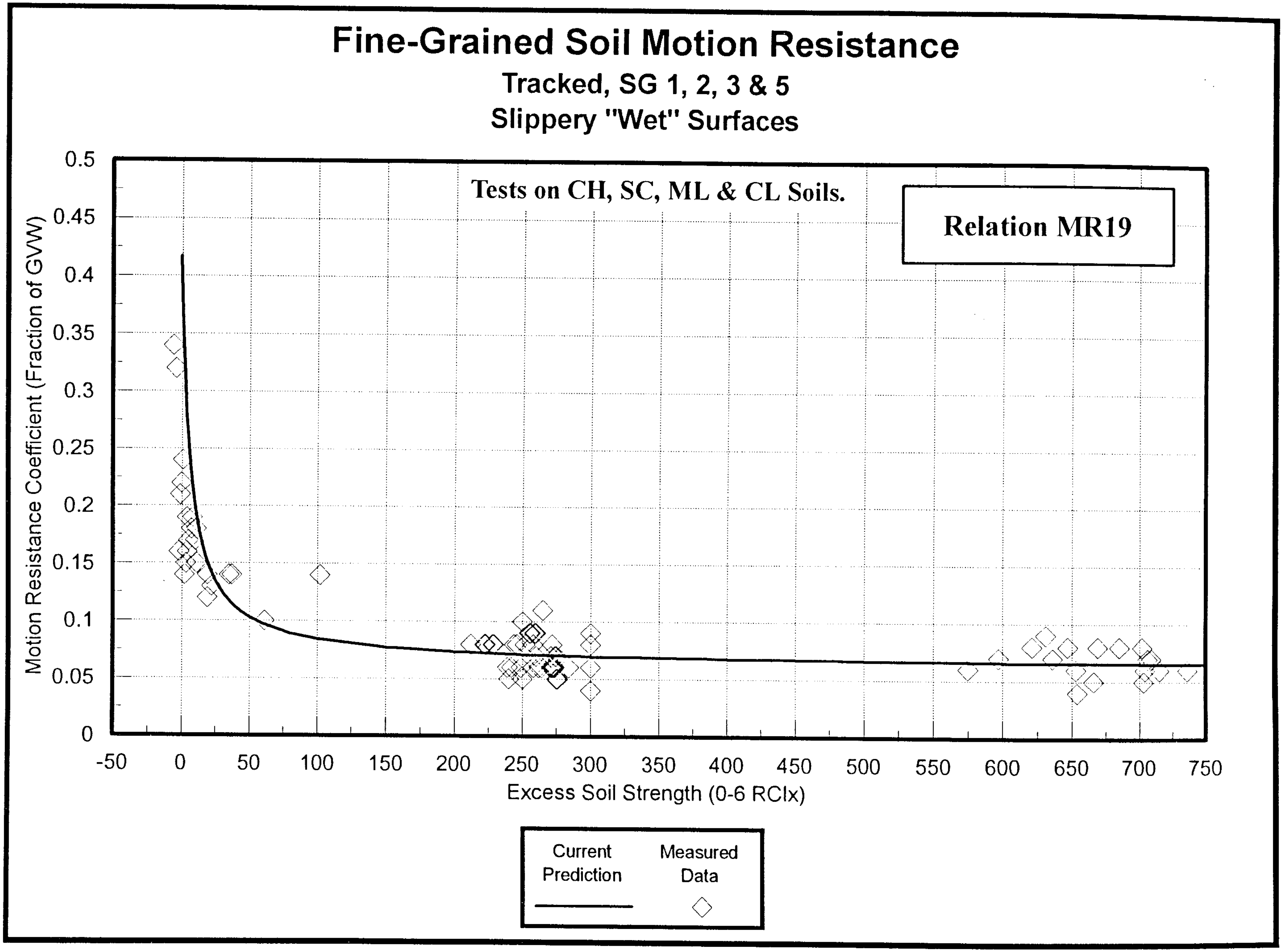
Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 1 & 2
Slippery "Wet" Surfaces
Tests on SC & CH Soils.
Relation MR15
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data

Fine-Grained Soil Motion Resistance

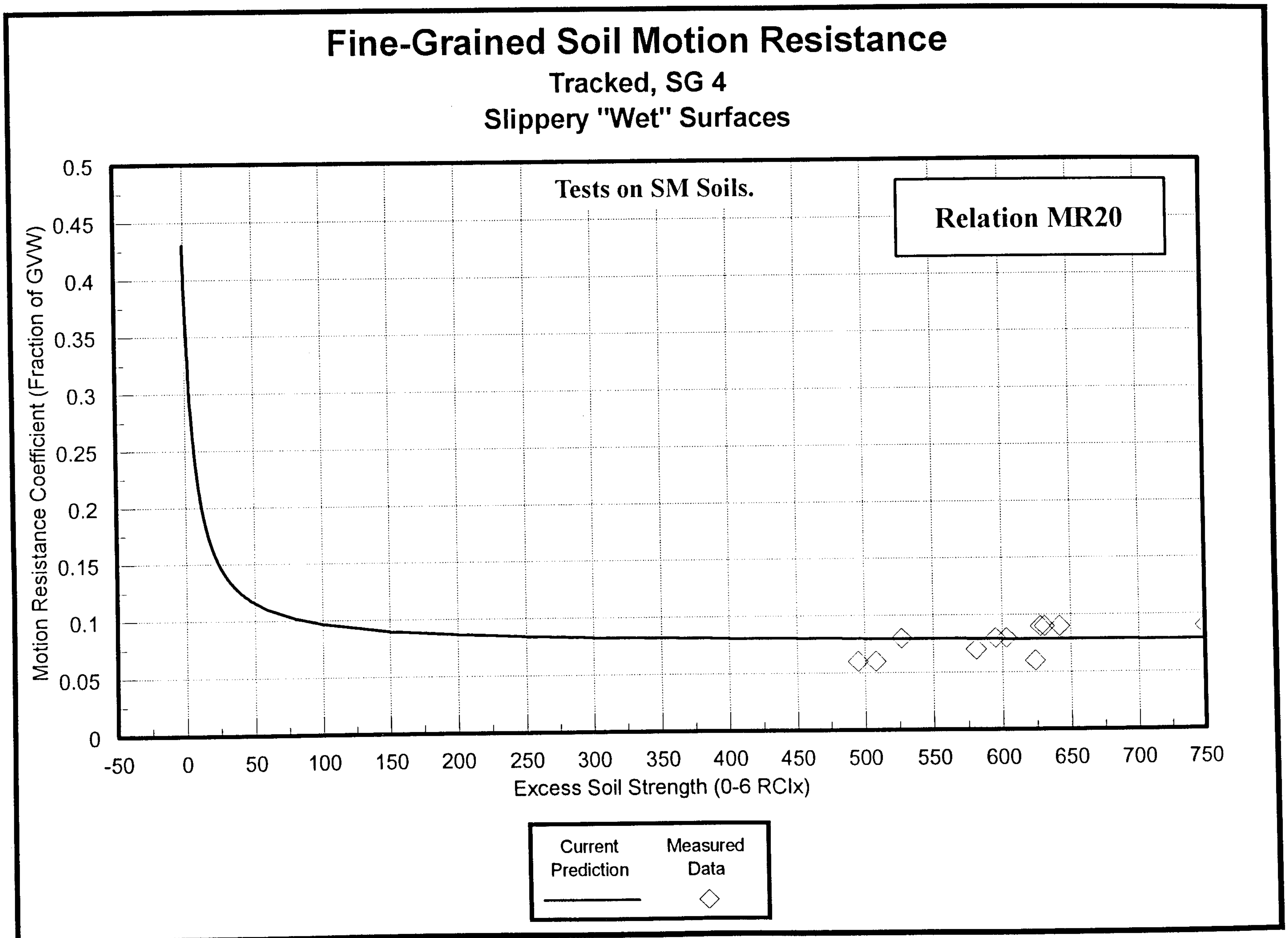
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 3 & 5
Slippery "Wet" Surfaces



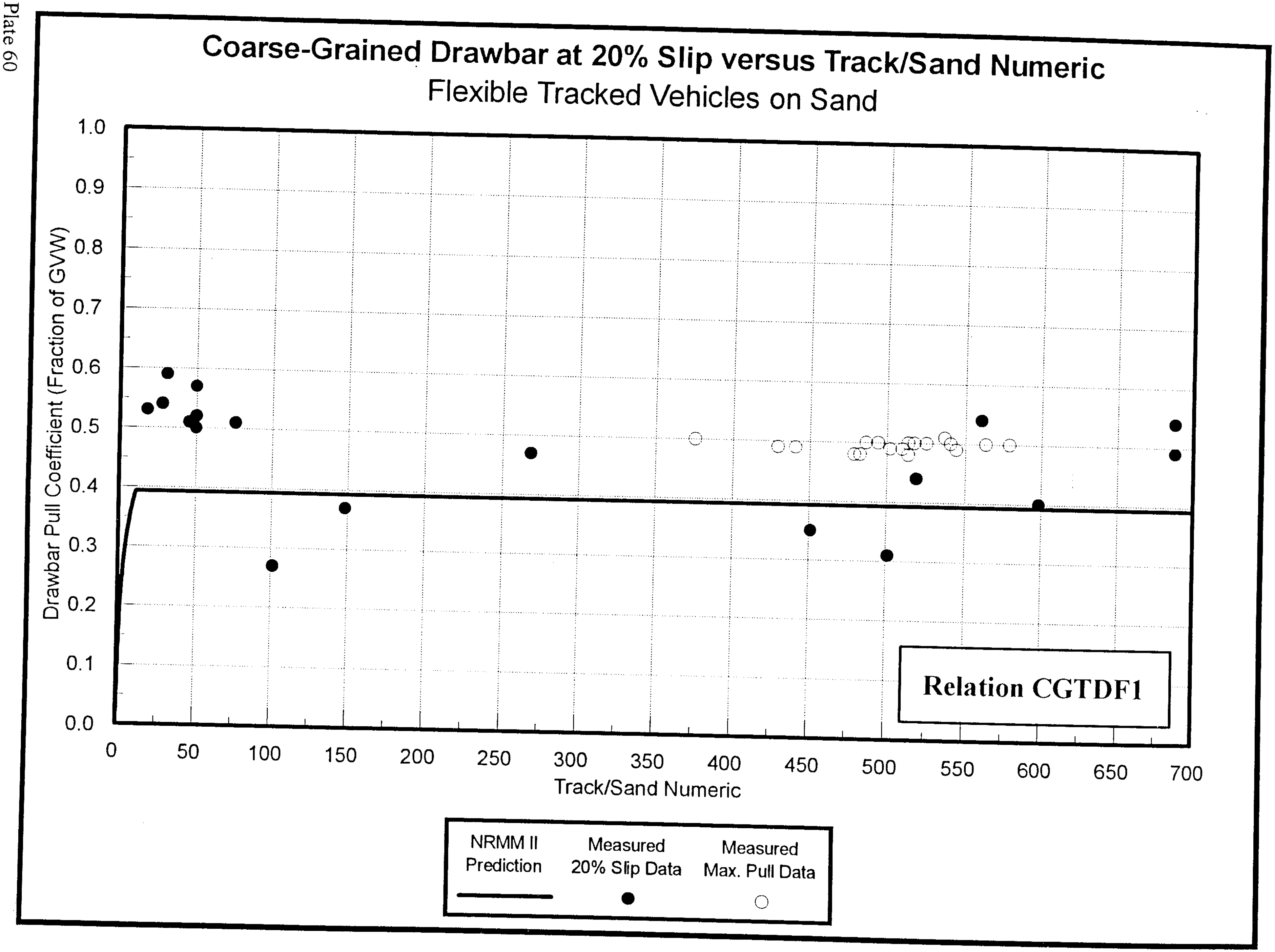

Fine-Grained Soil Motion Resistance
Powered Wheeled, CPF>=4psi, Bias Ply Tires, SG 4
Slippery "Wet" Surfaces
Tests on SM Soils.
Relation MR17
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data

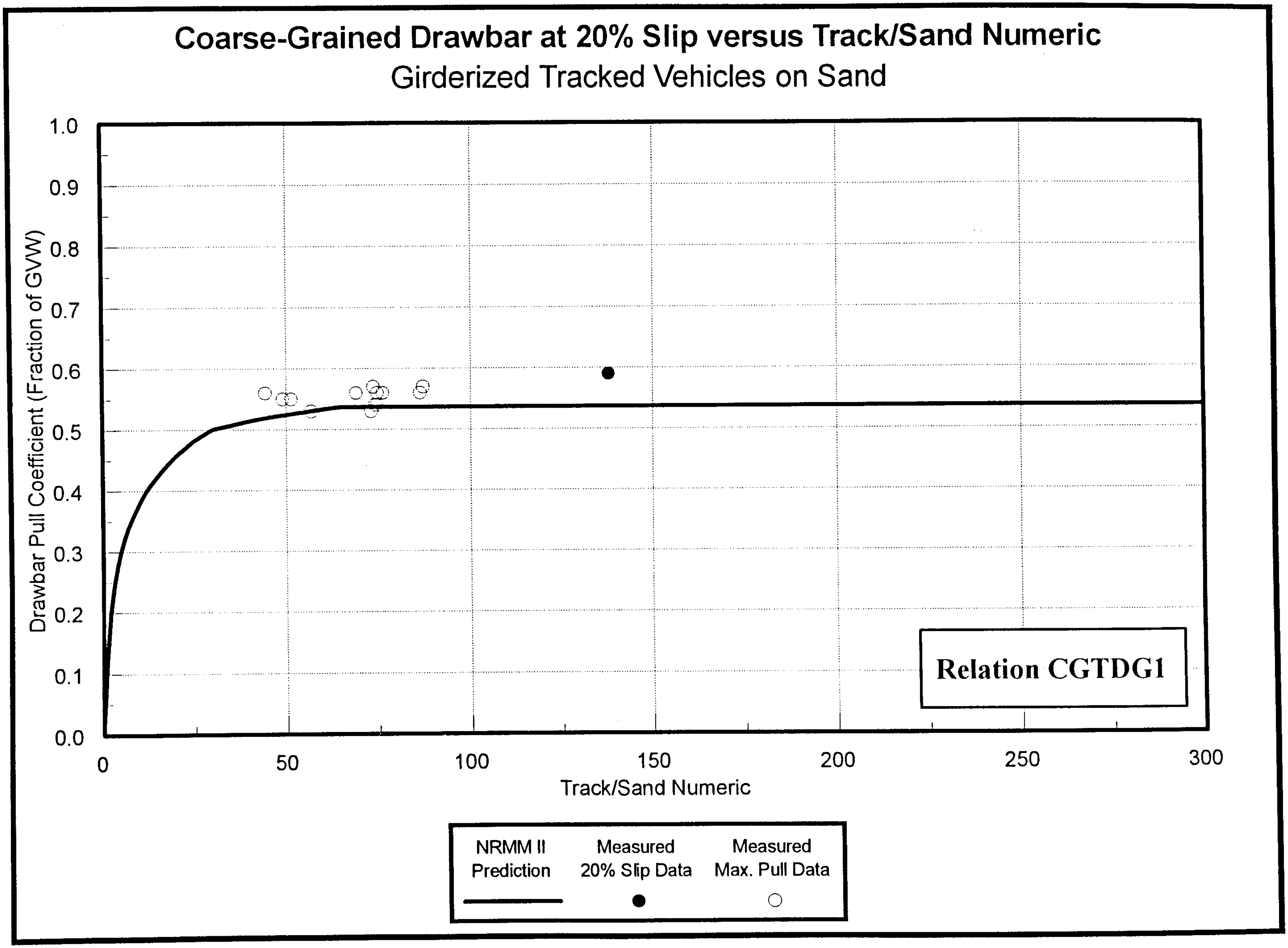


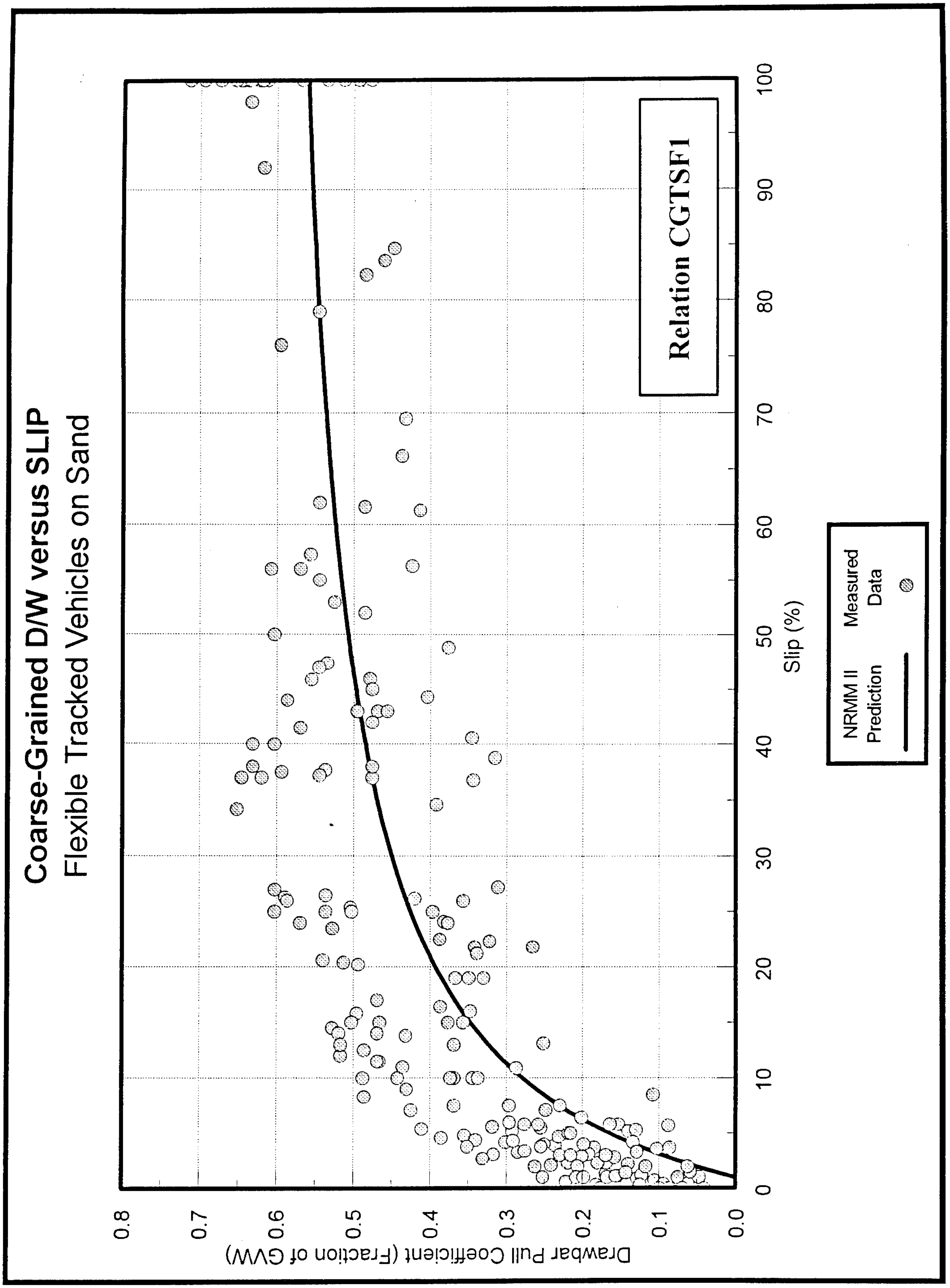
Fine-Grained Soil Motion Resistance
Tracked, SG 1, 2, 3 & 5
Slippery "Wet" Surfaces
Tests on CH, SC, ML & CL Soils.
Relation MR19
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data



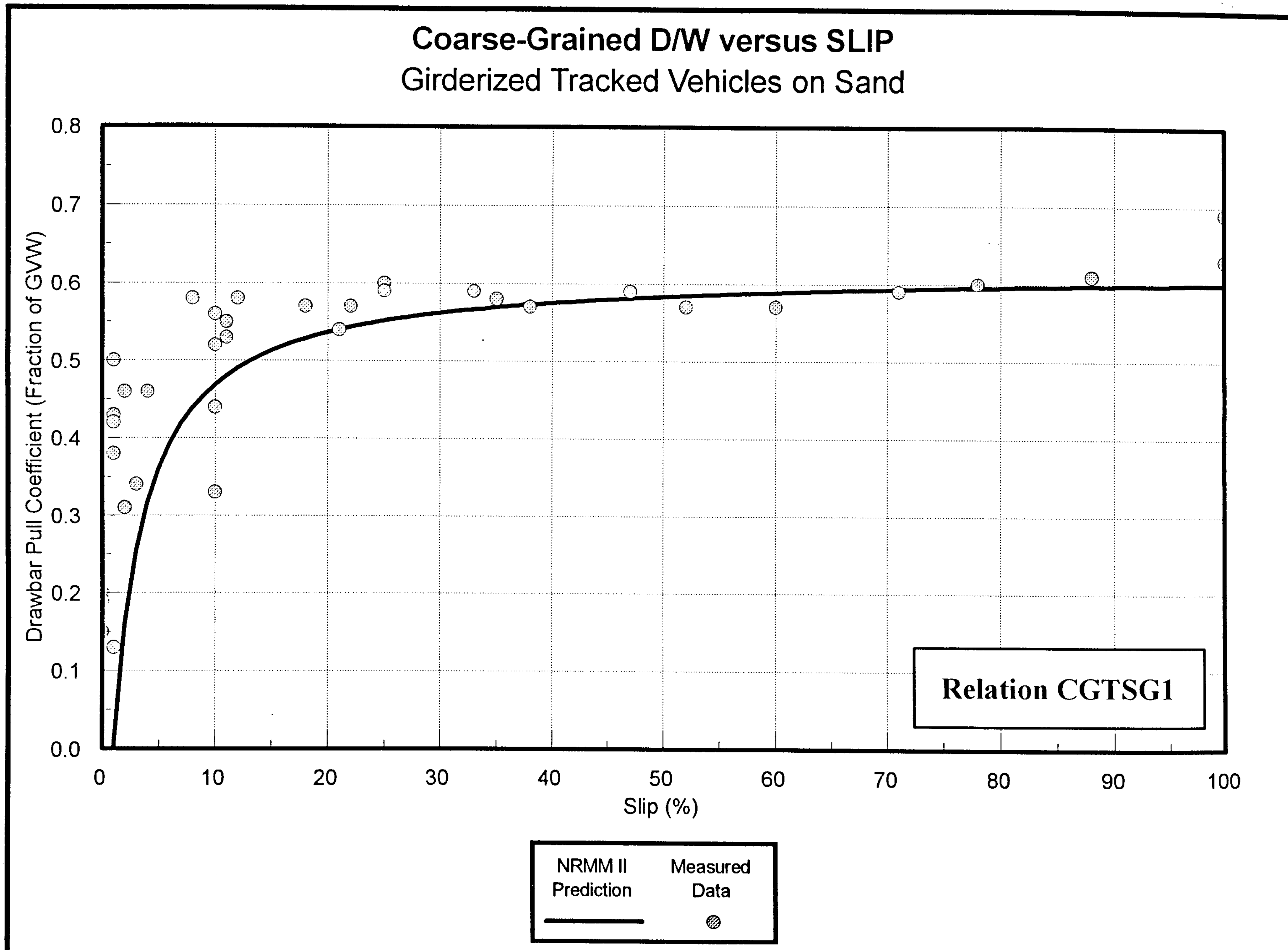
Fine-Grained Soil Motion Resistance
Tracked, SG 4
Slippery "Wet" Surfaces
Tests on SM Soils.
Relation MR20
Motion Resistance Coefficient (Fraction of GVW)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Excess Soil Strength (0-6 RCIx)
Current Prediction
Measured Data


Coarse-Grained Drawbar at 20% Slip versus Track/Sand Numeric
Flexible Tracked Vehicles on Sand
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Track/Sand Numeric
Relation CGTDF1
NRMM II Prediction
Measured 20% Slip Data
Measured Max. Pull Data

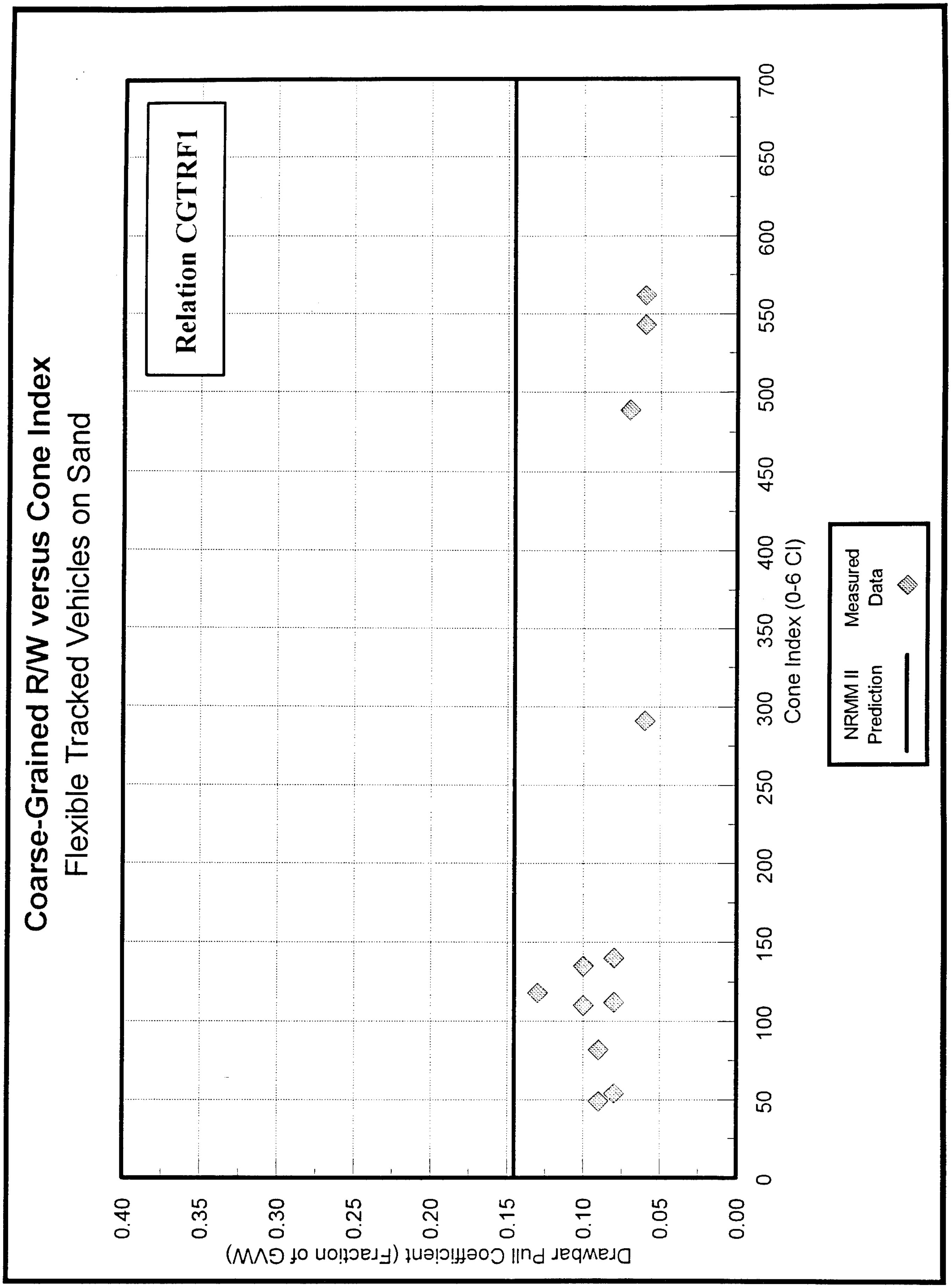

Coarse-Grained Drawbar at 20% Slip versus Track/Sand Numeric
Girderized Tracked Vehicles on Sand
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
Track/Sand Numeric
Relation CGTDG1
NRMM II Prediction
Measured 20% Slip Data
Measured Max. Pull Data



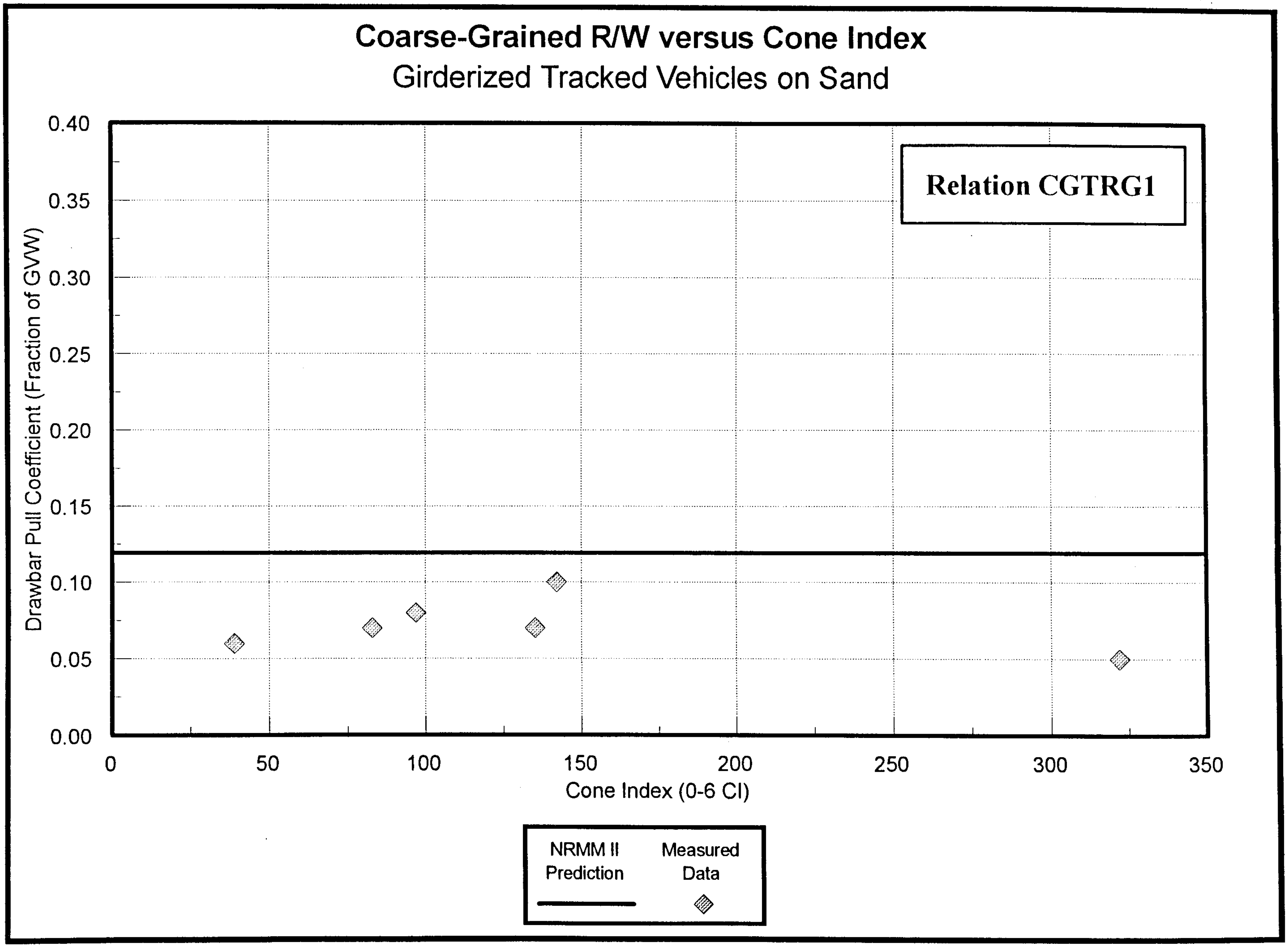
Coarse-Grained D/W versus SLIP
Flexible Tracked Vehicles on Sand
Relation CGTSF1
Drawbar Pull Coefficient (Fraction of GVW)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Slip (%)
0
10
20
30
40
50
60
70
80
90
100
NRMM II Prediction
Measured Data



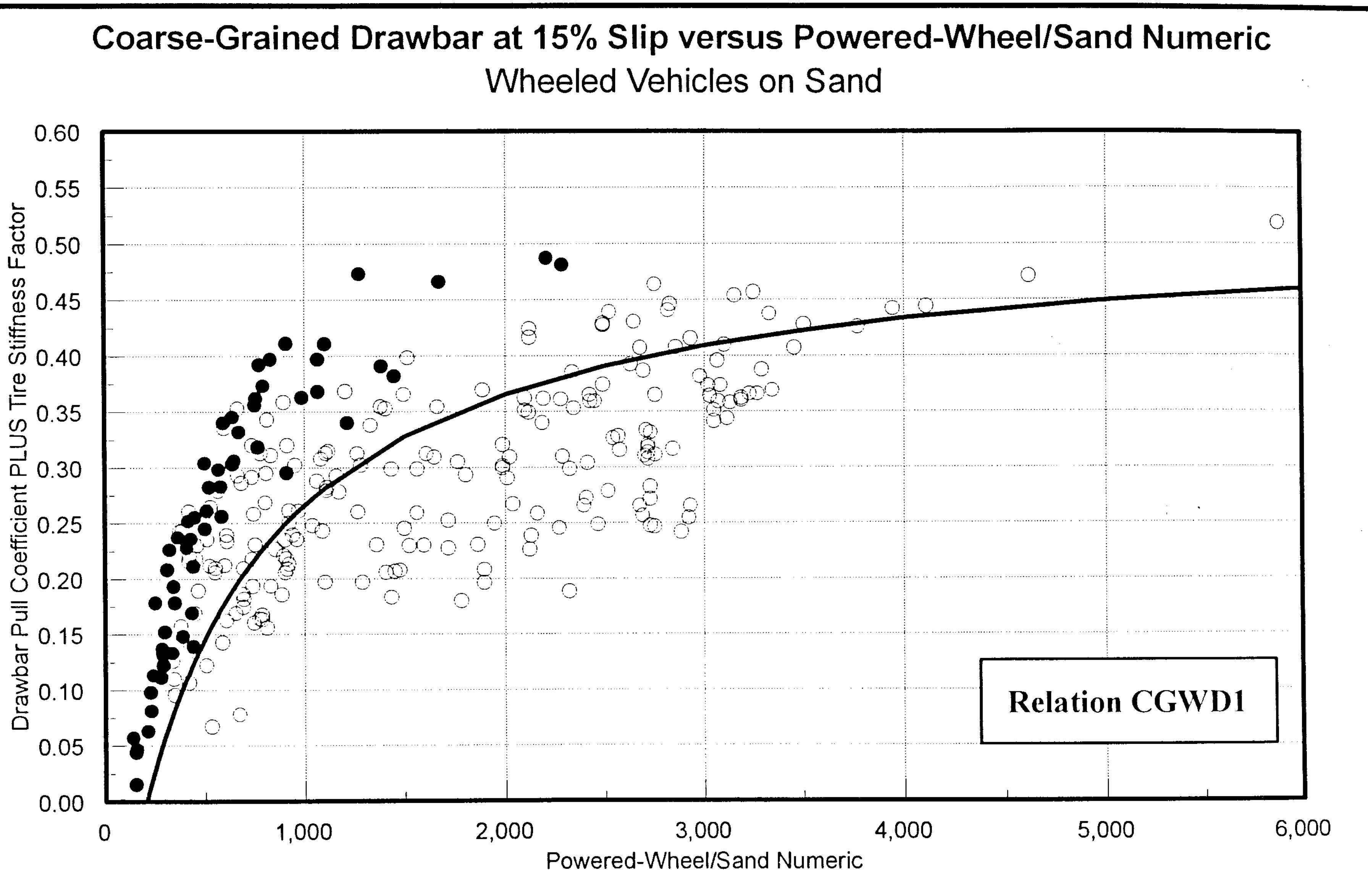
Coarse-Grained D/W versus SLIP
Girderized Tracked Vehicles on Sand
Drawbar Pull Coefficient (Fraction of GVW)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
10
20
30
40
50
60
70
80
90
100
Slip (%)
Relation CGTSG1
NRMM II Prediction
Measured Data



Coarse-Grained R/W versus Cone Index
Flexible Tracked Vehicles on Sand
Relation CGTRF1
Drawbar Pull Coefficient (Fraction of GVW)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Cone Index (0-6 CI)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
NRMM II Prediction
Measured Data



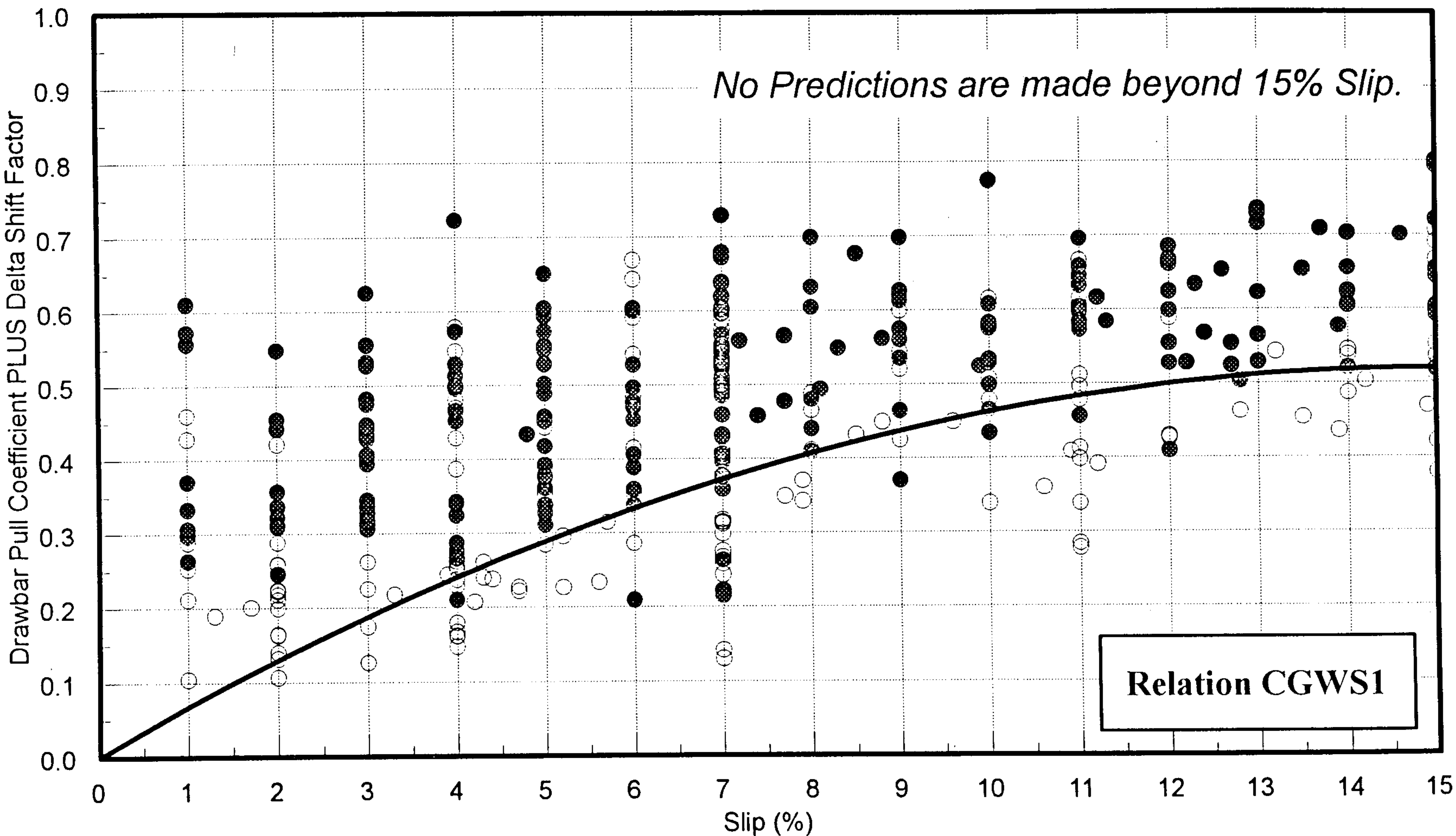
Coarse-Grained R/W versus Cone Index
Girderized Tracked Vehicles on Sand
Relation CGTRG1
Drawbar Pull Coefficient (Fraction of GVW)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
350
Cone Index (0-6 CI)
NRMM II Prediction
Measured Data



All measured data was taken from Table 11 (Lab data) and Table 12 (Field data) of Report 8 of Technical Report No. 3-666.

Soil Strength Correction Factor for Multiple Assembly Passes has been neglected since the data involves only 4x4 and 6x6 vehicles.

Coarse-Grained D/W versus SLIP
Wheeled Vehicles on Sand



DATA SOURCES

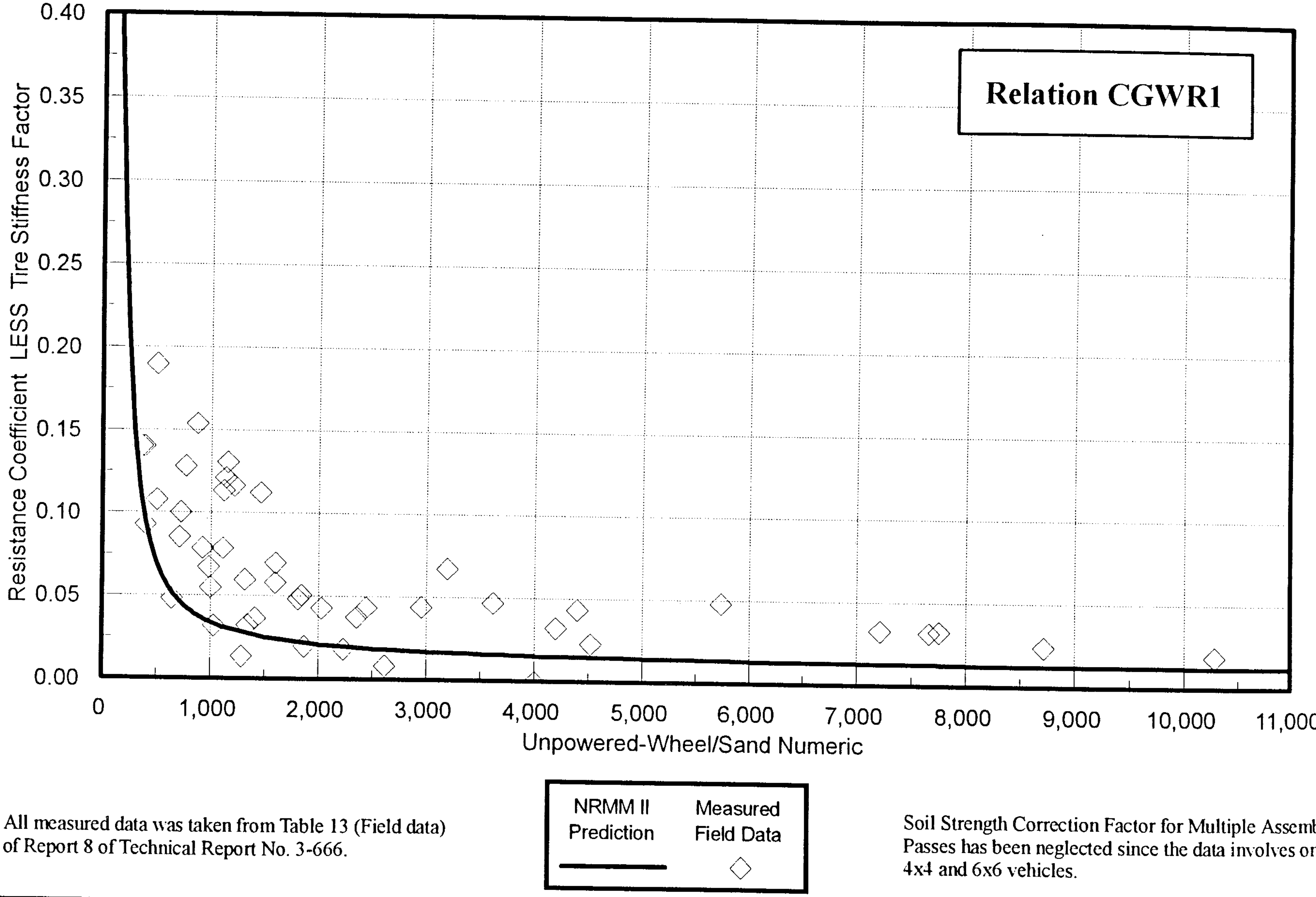
AMC-71 Validation Study, T.R. M-76-5, (Schreiner and Willoughby 1976) & HMMWV with CTIS Study, T.R. GL-92-7, (Jones 1992)

Measured Data 34 - 149 CI Range	Measured Data 489 - 600 CI Range	NRMM II Prediction "Max." Condition Curve
●	○	———

VEHICLES

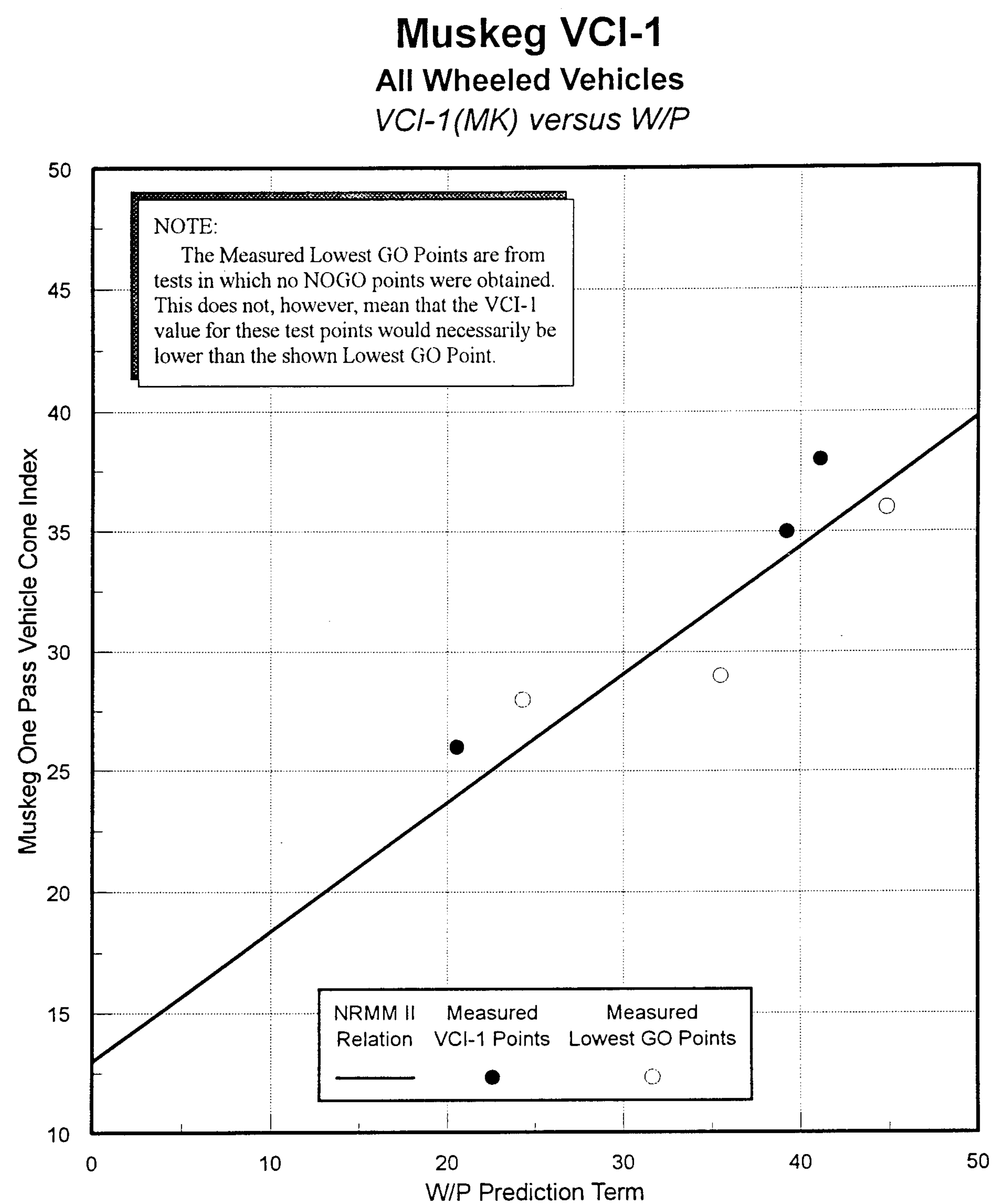
M35A2(mod) - 1 Bias Config.
M998 HMMWV - 1 Bias Config.
M998 HMMWV - 4 Radial Configs.
M1025 HMMWV - 4 Radial Configs.

Coarse-Grained Motion Resistance versus Unpowered-Wheel/Sand Numeric
Wheeled Vehicles on Sand



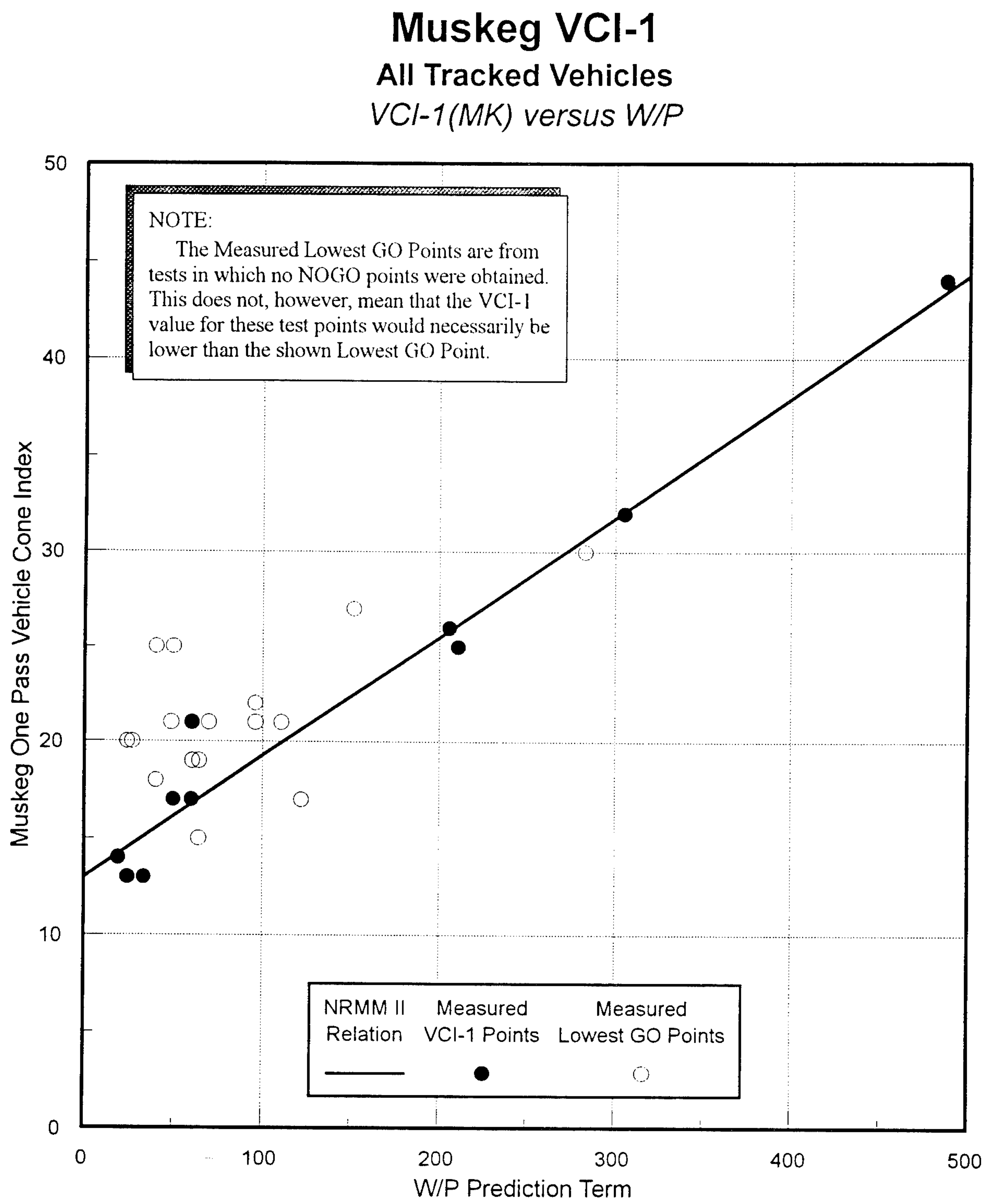
All measured data was taken from Table 13 (Field data) of Report 8 of Technical Report No. 3-666.

Soil Strength Correction Factor for Multiple Assembly Passes has been neglected since the data involves only 4x4 and 6x6 vehicles.



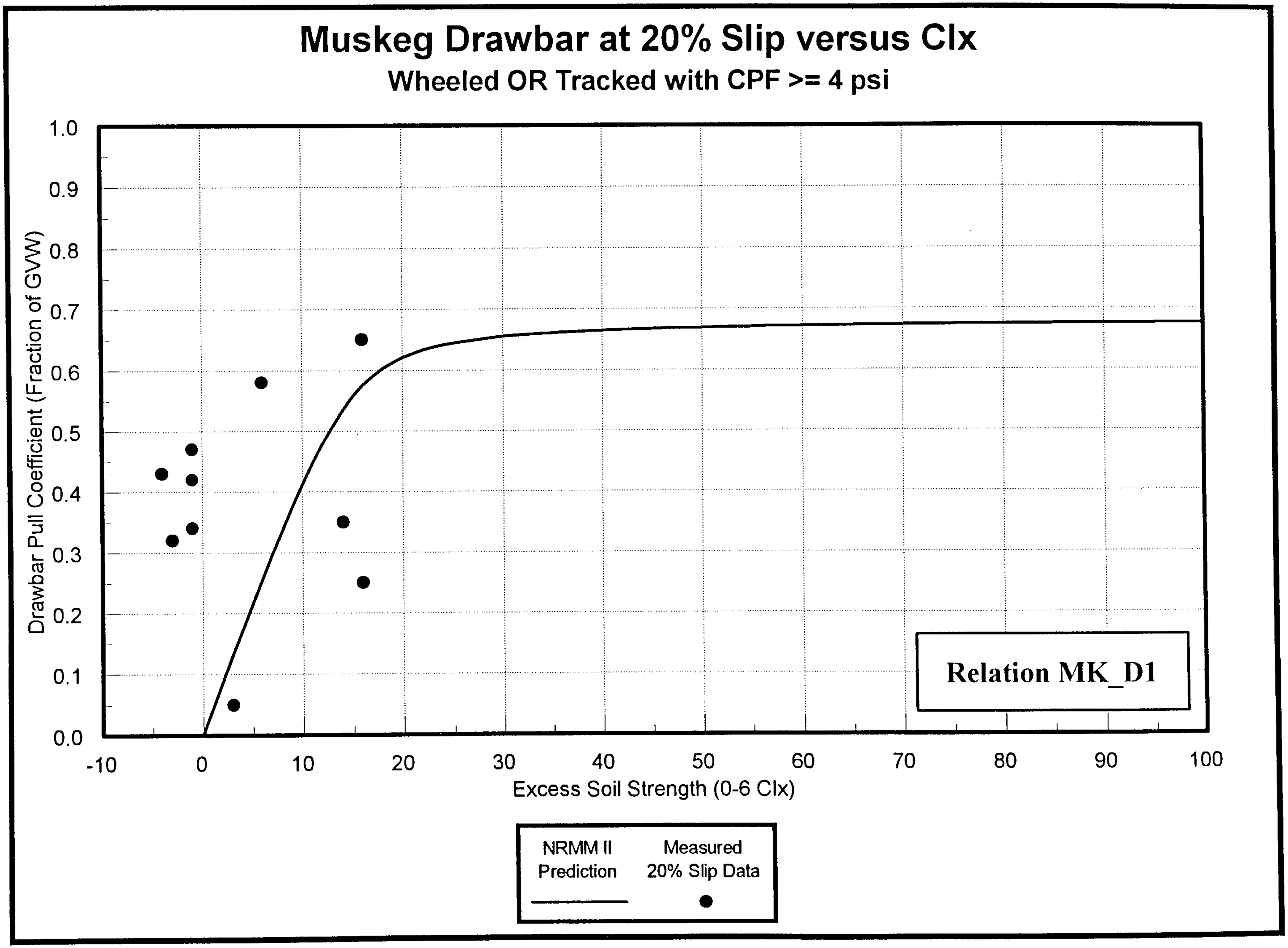
$$\frac{W}{P} = \frac{W}{(b+d)n}$$

Relation MK_VW1

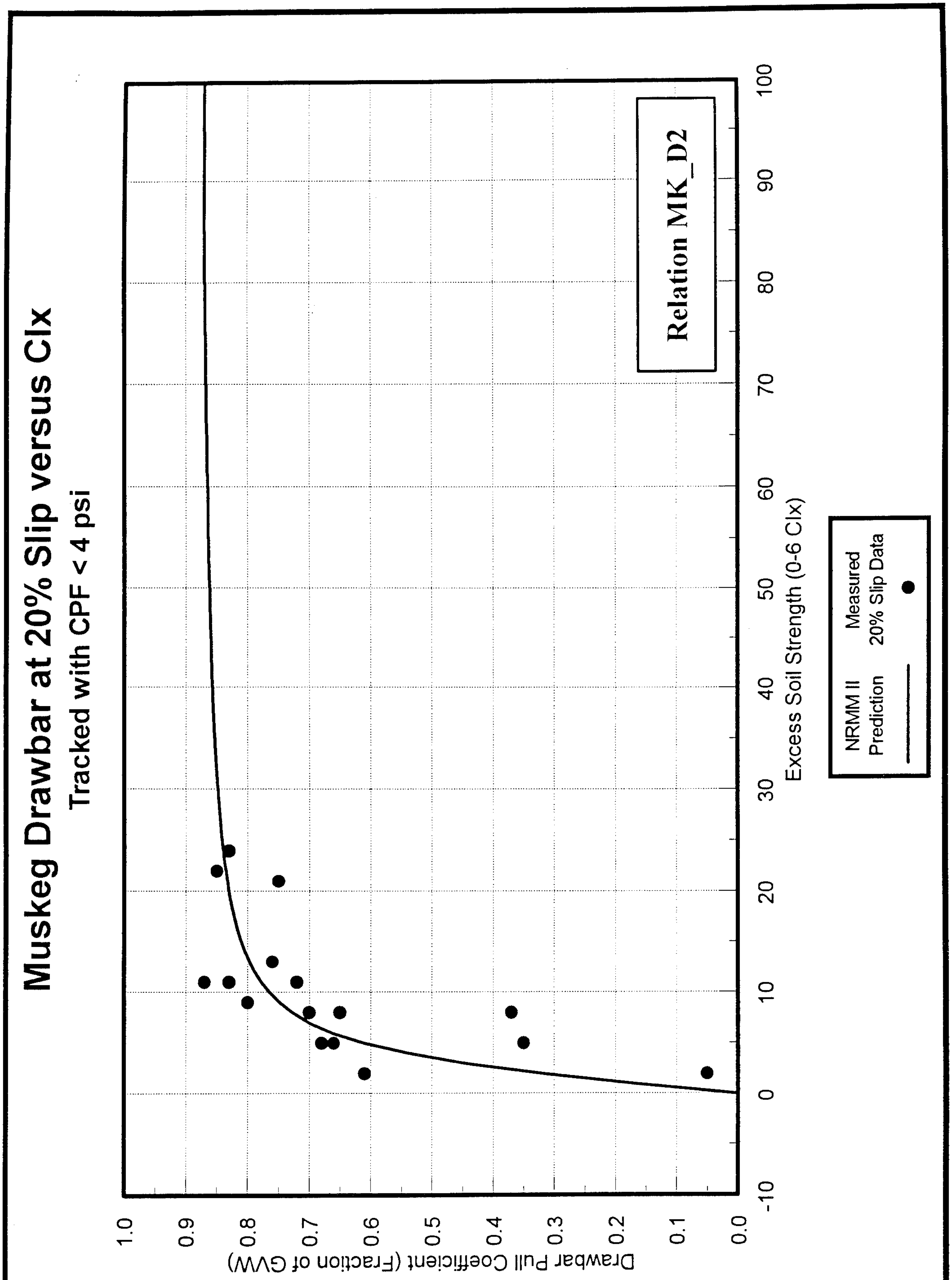


$$\frac{W}{P} = \frac{W}{(b+l)}$$

Relation MK_VT1

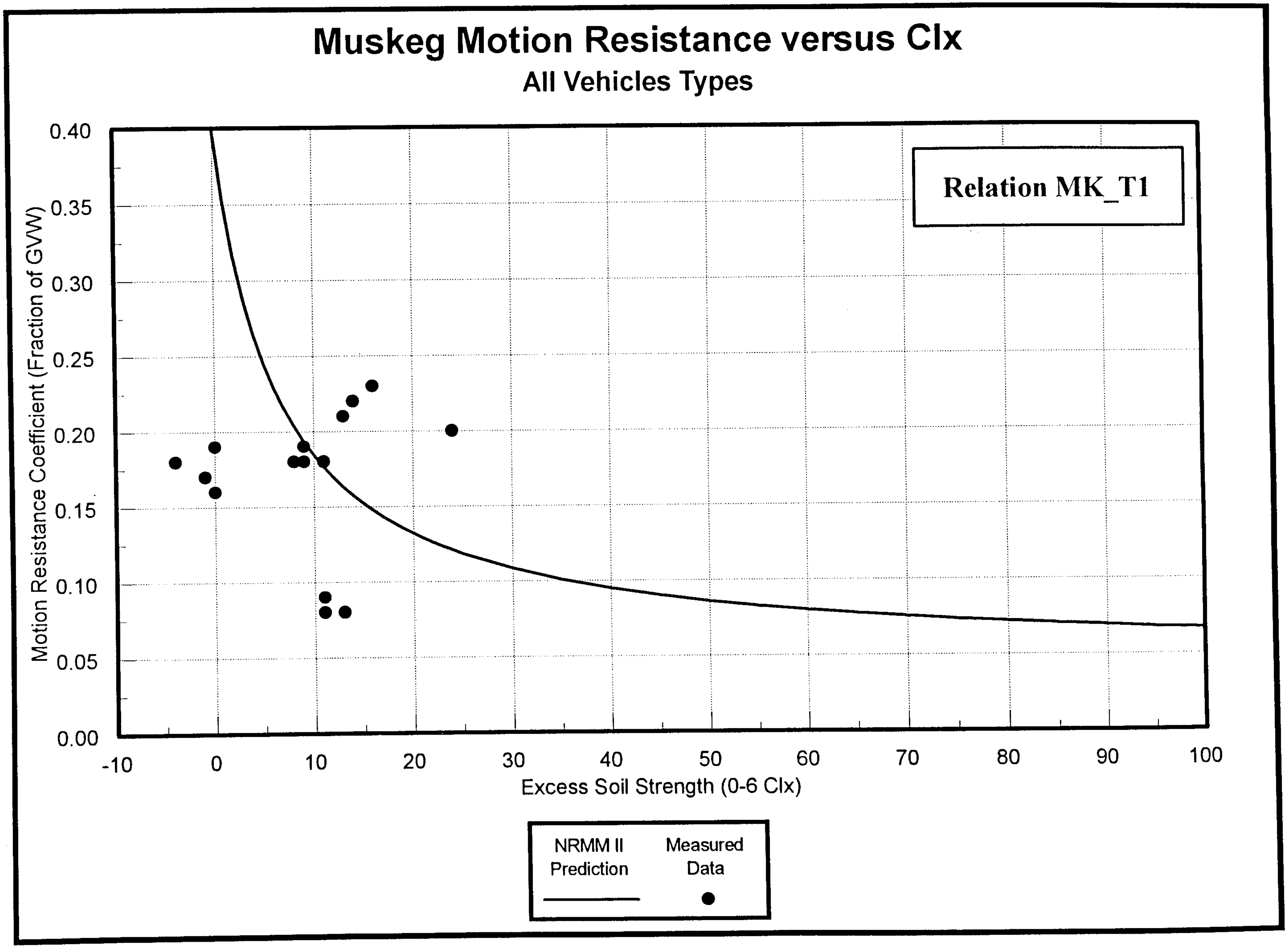


Muskeg Drawbar at 20% Slip versus CIx
Wheeled OR Tracked with CPF >= 4 psi
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-10
0
10
20
30
40
50
60
70
80
90
100
Excess Soil Strength (0-6 CIx)
Relation MK_D1
NRMM II Prediction
Measured 20% Slip Data



Muskeg Drawbar at 20% Slip versus CIx
Tracked with CPF < 4 psi
Relation MK_D2
Drawbar Pull Coefficient (Fraction of GVW)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-10
0
10
20
30
40
50
60
70
80
90
100
Excess Soil Strength (0-6 CIx)
NRMM II Prediction
Measured 20% Slip Data

Plate 72


Muskeg Motion Resistance versus CIx
All Vehicles Types
Relation MK_T1
Motion Resistance Coefficient (Fraction of GVW)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-10
0
10
20
30
40
50
60
70
80
90
100
Excess Soil Strength (0-6 CIx)
NRMM II Prediction
Measured Data

Appendix A Historical Test Procedures & Usage of Test Results for Establishing Relationships

Multi-pass Test

VCI_1 is not directly measurable. Rather it is interpreted from multi-pass test data. In a typical multi-pass test, a level, straight-line, homogeneous (as much as possible) test lane is marked off for the test, and then the vehicle makes passes through the test lane at a slow, steady state speed (≈2 mph) in its lowest gear. The test is usually conducted with the vehicle first driving forward through the test lane for pass number one and then driving backward (in reverse gear) through the test lane for pass number two. The vehicle will continue to make forward and backward passes until immobilization occurs. When immobilization is reached, the immobilization pass number is recorded, and soil consistency data are measured in a spot adjacent to the immobilization but out of the zone of disturbance. The measured soil strength is intended to represent the soil strength that is characteristic of the immobilizing pass number for the particular vehicle and terrain conditions.

To establish VCI_1 for a vehicle, several multi-pass tests are conducted on ranging soil strengths in order to compile a number of points for passes-made-good versus soil strength in the critical layer. The critical layer is the layer of soil (typically 3-9", 6-12", or 0-12") that contributes most significantly to the VCI_1 performance of the vehicle. The soil strength value at which the vehicle is capable of making one pass is then interpreted from a plot of the collected data for passes-made-good versus soil strength in the critical layer. This soil strength value is then referred to as the measured VCI_1 for the vehicle.

It should be noted that the measured One-Pass Vehicle Cone Index empirical relationships have historically not been established by fitting a best-fit curve to a plot of the measured VCI_1 versus MI data for all of the vehicles applicable to a particular relationship, as might be expected. Instead, all of the "root" multi-pass test data, GO and NOGO points, are plotted on a scatter plot of MI versus RCI in the critical layer. Then, a curve is established that best separates the GO from the NOGO points for all of the applicable vehicles. This allows all of the "root" test data to influence the empirical prediction relationship rather than just the interpreted VCI_1 points, which may vary some from one persons interpretation to another's.

Drawbar Pull - Slip Test

The drawbar pull - slip test is conducted to determine vehicle drawbar pull performance as a function of slip and soil strength. In the typical drawbar pull - slip test, a level, straight-line, homogeneous (as much as possible) test lane is marked off for the test, the lane is wetted or left dry depending on the desired test conditions, and then soil consistency data are measured in the lane, out of the zone of vehicle assembly passage. The test vehicle is linked-up to a load vehicle (usually a bulldozer) with a cable or strap, and a force load cell is connected between the vehicles within the linkage. The test vehicle is also instrumented so that the actual horizontal distance traveled and the apparent horizontal distance traveled, as indicated by assembly revolutions, can be measured.

The test vehicle enters the test lane followed by the load vehicle at a slow, steady state speed (≈2 mph). The load vehicle controls the test by controlling the force in the linkage load cell (drawbar pull force). It applies braking force in stepwise increments so that the test vehicle undergoes a stepwise transition from a zero pull, zero slip condition to a high pull, 100% slip condition. The test vehicle simply tries to maintain motion by applying more horsepower as necessary. The resulting measured data from the drawbar pull - slip test are drawbar pull, slip, and soil consistency for the particular vehicle and terrain conditions.

The drawbar pull - slip test data are typically used to establish two types of relationships. For the first type of relationship, the soil strength is held constant and a relationship between drawbar pull coefficient (D/W) and slip is established. This relationship is established for a vehicle by plotting measured D/W versus measured slip for a single drawbar pull - slip test condition (soil consistency) and then fitting a visual or statistical best-fit curve to the data. For the second type of relationship, the slip is held constant and a relationship between D/W and soil strength is established. This is more involved since it is typically not possible to operate a vehicle at a constant level of slip over a test lane of varying soil strength. To establish this type of relationship for a vehicle, many drawbar pull - slip tests are conducted on a number of different soil strengths. Then the measured D/W data are plotted versus the measured slip data for each test and a visual or statistical best-fit curve is fit to the data for each test. Then D/W at some constant slip (usually 20% or optimum) is interpreted from each of the best-fit curves for D/W versus slip. Finally, these interpreted D/W data are plotted versus the measured soil strength data from all of the tests, and a visual or statistical best-fit curve is fit to the

D/W versus soil strength data.

Maximum Drawbar Pull Test

The maximum drawbar pull test is conducted to determine a vehicle's maximum drawbar pull performance as a function of soil strength. No consideration is given to slip. In the typical maximum drawbar pull test, a level, straight-line, homogeneous (as much as possible) test lane is marked off. The test vehicle is linked-up to a load vehicle (usually a bulldozer) with a cable or strap, and a force load cell is connected between the vehicles within the linkage. The test vehicle then enters the test lane followed by the load vehicle at a slow, steady state speed (≈2 mph). The load vehicle controls the test by controlling the force in the linkage load cell (drawbar pull force). It slowly applies more and more braking force until it stops the forward progress of the test vehicle. The test vehicle simply tries to maintain motion by applying more horsepower as necessary. After the test, soil consistency data are measured adjacent to the point of maximum pull but out of the zone of disturbance. The resulting measured data from the maximum drawbar pull test are maximum drawbar pull and soil strength for the particular vehicle and terrain conditions.

The maximum drawbar pull test data are typically used to establish maximum drawbar pull coefficient (D/W_{MP}) versus soil strength relationships. Maximum drawbar pull tests are conducted on many different soil strengths for a particular vehicle. Then D/W_{MP} is plotted versus soil strength, and a visual or statistical best-fit curve is fit to the data to establish the relationship for the vehicle.

The maximum drawbar pull test was a precursor to the drawbar pull - slip test. This test was originally designed ignoring slip because slip information was not desired and because the test is more simple to conduct and analyze. Slip became desirable information when the modeling focus shifted towards predicting speed in the late nineteen sixties, and therefore, the drawbar pull - slip test was designed and became the standard test for obtaining D/W versus soil strength information.

Towed Motion Resistance Test

The towed motion resistance (TMR) test is conducted to determine a vehicle's motion resistance performance as a function of soil strength. In the typical TMR test, a level, straight-line, homogeneous (as much as possible) test lane is marked off for the test, the lane is wetted or left dry depending on the desired test conditions, and then soil consistency data are measured in the lane, out of the zone of vehicle assembly passage. The test vehicle is linked-up to a control vehicle (usually a bulldozer) with a cable or strap, and a force load cell is connected between the vehicles within the linkage. The test vehicle is put into neutral gear (unpowered assemblies), and then the control vehicle pulls the test vehicle through the test lane at a slow steady state speed (≈2 mph) over a long enough period of time for the average motion resistance force to be determined. The resulting measured data from the TMR test are motion resistance force (i.e. rolling resistance force) and soil strength for the particular vehicle and terrain conditions.

The TMR test data are typically used to establish motion resistance coefficient (R/W) versus soil strength relationships, or more specifically, rolling resistance coefficient relationships. TMR tests are conducted on many different soil strengths with a particular vehicle. Then R/W is plotted versus soil strength, and a visual or statistical best-fit curve is fit to the data to establish the relationship for the vehicle.

Appendix B
Current Names and Locations of the Database Files

The digital database files have been created using Quattro Pro for Windows (QPW) Version 1.0, but they can be translated into most other major spreadsheet software formats, ASCII format, and even some major database software formats. The databases are currently accessible on the Mobility Systems Division's SUN 4/690 (gml690). The databases are located in the directory path **home8/gml690/jody/FINAL_Databases**. The internal directory structure is illustrated in Figure B1.

```
FINAL_Databases
  └──────────── traction
          ├──────────── c-gmodel
          │        ├──────────── tracked
          │        │        ├──────────── dbp-pi_t
          │        │        ├──────────── mr
          │        │        └──────────── slip-dbp
          │        └──────────── wheeled
          │                 ├──────────── dbpANDmr
          │                 └──────────── slip-dbp
          ├──────────── f-gmodel
          │        ├──────────── dbp-rcix
          │        │        ├──────────── rejects
          │        │        ├──────────── tracked
          │        │        └──────────── wheeled
          │        ├──────────── mr-rcix
          │        ├──────────── slip-dbp
          │        │        ├──────────── rejects
          │        │        ├──────────── tracked
          │        │        └──────────── wheeled
          │        └──────────── vci-1_fg
          └──────────── muskeg
                   ├──────────── dbp-cix
                   ├──────────── mr-cix
                   ├──────────── slip-dbp
                   └──────────── vci-1_mk
```

Figure B1. Directory structure for the cross-country traction database files

The following sections provide the current digital database file names and locations on gm1690. For assistance, some general information about the layout of the files is also provided. It is assumed that the reader, or file user, is familiar with 3-dimensional spreadsheet software.

Vehicles on Fine-Grained Soils

Fine-Grained One-Pass Vehicle Cone Index

The *Fine-Grained One-Pass Vehicle Cone Index* database is contained in one file named MEASVCI1.WB3. Both tracked vehicle data and wheeled vehicle data are contained on a single spreadsheet, but the entries are sorted listing wheeled vehicle entries first and tracked vehicle entries second. The file is located in the directory FINAL_Databases/traction/f-gmodel/vci-1_fg.

Fine-Grained Drawbar at Nominal Slip

The *Fine-Grained Drawbar at Nominal Slip* database exists in two forms. In the first form, there are two big database files that contain all of the data for all of the relationships, one containing wheeled vehicle data and the other containing tracked vehicle data. The name of the wheeled file is DBRCIXWE.WB1, and the name of the tracked file is DBRCIXTD.WB1. These two database files do not contain the predictions. In the second form, there are 16 smaller files that only contain data applicable to a single NRMM II relationship at a single slip condition, 20% or 100%. The names of these files are listed below:

100% Database	20% Database
(1) 100%ER01.WB1	(9) 20%ER01.WB1
(2) 100%ER2A.WB1	(10) 20%ER2A.WB1
(3) 100%ER2B.WB1	(11) 20%ER2B.WB1
(4) 100%ER03.WB1	(12) 20%ER03.WB1
(5) 100%ER04.WB1	(13) 20%ER04.WB1
(6) 100%ER05.WB1	(14) 20%ER05.WB1
(7) 100%ER06.WB1	(15) 20%ER06.WB1
(8) 100%ER7A.WB1	(16) 20%ER7A.WB1

There are 19 files in all counting the "rejects" file, which is named DBREJECT.WSN. The wheeled files are located in the directory FINAL_Databases/traction/f-gmodel/dbp-rcix/wheeled, the tracked files are located in the directory FINAL_Databases/traction/f-gmodel/dbp-rcix/tracked, and the "rejects" file is located in the directory FINAL_Databases/traction/f-gmodel/dbp-rcix/rejects.

Fine-Grained Slip at "Maximum" Soil Strength

The *Fine-Grained Slip at "Maximum" Soil Strength* database exists in single files for each of the slip relationships plus a single "reject" file. There are 12 wheeled files and 12 tracked files for the slip relationships. The names of these files are listed below:

WHEELED	TRACKED
(1) F-G_ER08.WB1	(13) F-G_ER13.WB1
(2) F-G_ER09.WB1	(14) F-G_ER14.WB1
(3) F-G_ER10.WB1	(15) F-G_ER15.WB1
(4) F-G_ER11.WB1	(16) F-G_ER23.WB1
(5) F-G_ER12.WB1	(17) F-G_ER24.WB1
(6) F-G_ER16.WB1	(18) F-G_ER25.WB1
(7) F-G_ER17.WB1	(19) F-G_ER26.WB1
(8) F-G_ER18.WB1	(20) F-G_ER27.WB1
(9) F-G_ER19.WB1	(21) F-G_ER28.WB1
(10) F-G_ER20.WB1	(22) F-G_ER29.WB1
(11) F-G_ER21.WB1	(23) F-G_ER30.WB1
(12) F-G_ER22.WB1	(24) F-G_ER31.WB1

The wheeled files are located in the directory FINAL_Databases/traction/f-gmodel/slip-dbp/wheeled, and the tracked files are located in FINAL_Databases/traction/f-gmodel/slip-dbp/tracked. The "reject" file is named SLIPRJCT.WB1, and it is in the directory FINAL_Databases/traction/f-gmodel/slip-dbp/rejects. Predicted performance information is not included in the database files, but a file is provided that contains the prediction equations. This file is named SLIPCRVS.W_N, and it is located in the directory FINAL_Databases/traction/f-gmodel/slip-dbp.

Fine-Grained Motion Resistance

The *Fine-Grained Motion Resistance* database is contained in one file named MR-RCIX.WB3. The file is divided into four primary spreadsheets: (1) Dry Powered Wheeled, (2) Wet Powered Wheeled, (3) Dry Tracked, and (4) Wet Tracked. The database also contains spreadsheets with the data from the original database that were "rejected". The "rejects" are contained in two secondary spreadsheets: (1) Wheeled, and (2) Tracked. The file is located in the directory FINAL_Databases/traction/f-gmodel/mr-rcix.

Tracked Vehicles on Coarse-Grained Soils

Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils

The *Tracked Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database is contained in one file named DBPVSCI.WB1. The file contains two spreadsheets, one for the 20% slip data and one for the 40% slip data. Each spreadsheet is divided into a flexible tracked vehicle area and a girderized tracked vehicle area. The file is located in the directory FINAL_Databases/traction/c-gmodel/tracked/dbp-pi_t.

Tracked Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils

The *Tracked Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database is contained in one file named C-GSLIPT.WB1. The file is divided into a flexible tracked vehicle spreadsheet and a girderized tracked vehicle spreadsheet. The file is located in the directory FINAL_Databases/traction/c-gmodel/tracked/slip-dbp.

Tracked Vehicle Motion Resistance on Coarse-Grained Soils

The *Tracked Vehicle Motion Resistance on Coarse-Grained Soils* database is contained in one file named TMRVSCI.WB1. The file is divided into two spreadsheets, one for flexible tracked vehicle data and one for girderized tracked vehicle data. The file is located in the directory FINAL_Databases/traction/c-gmodel/tracked/mr.

Wheeled Vehicles on Coarse-Grained Soils

Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils

The file containing the *Wheeled Vehicle Drawbar at Nominal Slip on Coarse-Grained Soils* database is named COAR.WB1. The file is divided into two areas: (1) an area for drawbar data, and (2) an area for motion resistance data. The drawbar area is located at the top of a single spreadsheet, directly above the motion resistance area. The file is located in the directory FINAL_Databases/traction/c-gmodel/wheeled/dbpANDmr.

Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils

The *Wheeled Vehicle Slip at "Maximum" Soil Strength on Coarse-Grained Soils* database is contained in one file named C-GSLIPW.WB3. The file is divided into two large areas. One area contains the data from testing on high CI soils and the other area contains the data from testing on low CI soils. The high CI area is located above the low CI area. The file is located in the directory FINAL_Databases/traction/c-gmodel/wheeled/slip-dbp.

Wheeled Vehicle Motion Resistance on Coarse-Grained Soils

The file containing the *Wheeled Vehicle Motion Resistance on Coarse-Grained Soils* database is named COAR.WB1. It is divided into two areas: (1) an area for drawbar data, and (2) an area for motion resistance data. The motion resistance area is located directly below the drawbar area on a single spreadsheet. The file is located in the directory FINAL_Databases/traction/c-gmodel/wheeled/dbpANDmr.

Vehicles on Muskeg

Muskeg One-Pass Vehicle Cone Index

The *Muskeg One-Pass Vehicle Cone Index* database is contained in two files, one for tracked vehicle data and one for wheeled vehicle data. The tracked file is named MK_VCI-T.WB1. The wheeled file is named MK_VCIW.WB1. Both files are located in the directory FINAL_Databases/traction/muskeg/vci-1_mk.

Muskeg Drawbar at Nominal Slip

The *Muskeg Drawbar at Nominal Slip* database is contained in one file named MK_DBP.WB1. The file is divided into two major spreadsheets, one for each of the two Muskeg Drawbar at Nominal Slip relationships. It is located in the directory FINAL_Databases/traction/muskeg/dbp-cix.

Muskeg Slip at "Maximum" Soil Strength

No digital database was developed for the Muskeg Slip at "Maximum" Soil Strength relationships.

Muskeg Motion Resistance

The *Muskeg Motion Resistance* database is contained in one file named MK_TMR.WB1. All of the data, both tracked and wheeled, are contained on one spreadsheet since there is only one Muskeg Motion Resistance relationship in NRMM II. The file is located in the directory FINAL_Databases/traction/muskeg/mr-cix.

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13. ABSTRACT *(Maximum 200 words)*

This report is the third in a series that documents the progression of a research effort aimed at developing stochastic vehicle mobility forecasting capabilities using the NATO Reference Mobility Model, edition II (NRMM II). The first report introduced the basic concepts and procedures. The second report described extensions of the procedures and demonstrated the application of these procedures to two historical mobility assessments that were influential in the procurement of some current U.S. Army vehicles. The procedures described in these first two reports characterized the variability of the NRMM II empirical relationships using small-scale data sets and/or judgment. The intent was only to demonstrate the viability of the stochastic forecasting concepts.

The effort reported in this third report was conducted to facilitate a more accurate characterization of the variability in the cross-country traction empirical relationships. The approach was to: (1) thoroughly examine the empirical relationships in terms of fundamental origins and implemented use, and (2) economically develop a database that will accurately characterize the variability of each relationship. As a result, databases were developed for 65 of the 70 NRMM II empirical relationships for vehicle traction on soil covered terrain, and these databases will facilitate at least a conjectural evaluation of the variability in all 70. When variability characterizations based on these new databases are implemented (continued on back)

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into the stochastic forecasting procedures, more accurate risk assessments will result.

Another result of this research was the observation that some of the NRMM II traction relationships are in need of attention for model improvements. Quick improvements were possible for some, and these improvements are proposed for implementation into NRMM in this report. For others it was feasible only to make recommendations for future improvements.